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Motion Sickness in Virtual Reality: An Empirical Evaluation

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ABSTRACT Due to rapid growth in Virtual Reality (VR) technology, the industry of VR is expected to grow around $26.89 billion by 2022. However, with its extensive growth and immersive inclusion in human life, health-related issues are reported including, but not limited to nauseated feeling, vomiting, dizziness and cold sweats. These issues introduce a well-known side effect termed as motion sickness in VR users. Consequently, motion sickness limits the VR community in the full adaptation of this immersive technology. Since there is no lack of literature investigating motion sickness caused by VR, yet researches on the effect of VR on human's physiology is still in its infancy. This study presents novel findings, by comparing different factors such as gender, motion sickness experience, 3D games experience and VR experience. Furthermore, it reports the impact of concerning factors in a within-subjects design (46 participants participated in an experiment) under different virtual environment genres. The key findings of this article report that there is a significant difference in the amount of motion sickness when shifting from pleasant to the horror genre of the environment and having a strong dependence on gender. Moreover, the type of virtual environment is an essential factor that has a notable effect on the user's blood pressure, blood sugar and heart rate. However, past experiences with motion sickness and 3D games show no significant impact on the user's level of motion sickness.

INDEX TERMS Motion sickness, simulator sickness, virtual reality, virtual worlds, virtual environments, VR sickness.

I. INTRODUCTION

VR is a computer-simulated experience that mimics various physical surroundings to facilitate its users. VR technology generates a virtual environment by amplifying three-dimensional characters, situations or objects, which altogether increase the realistic sensation of this technology. To provide best VR experiences, the virtual environments are developed in a way that replaces user's cognition with computer-simulated sensations, i.e. contravening the users from the real world [1]. To fully benefit from VR technology, different VR hardware are offered that are cheap and readily available inundating the market of VR. To achieve the full immersion of the virtual environment, these VR hardware devices are connected with VR supported applications to provide a realistic alternate environment. The most common and top of the line hardware devices that fully immerse users into virtual environments are the Head-Mounted Displays (HMDs). HMDs are VR headsets that are affordable, readily available and provide complete immersion into virtual environments. The immense growth of science has the potential to inculcate further applications with HMD to provide the best VR experiences.

Due to its engulfing nature, VR has already become a mainstream focus in different industries [2] ranging from healthcare [3], image processing [4], medicine [5], firefighting [6], automotive, military [6], real estate, architecture, social networking, education, sports, entertainment and gaming [7]. On one hand, it is reported that the industry of VR is expected to reach $26.89 billion by 2022 [8]. While on

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the other hand, with the extensive growth of VR technology [7], [9] and its deep inclusion in human life, many issues related to health such as nausea, dizziness, cold sweats and vomiting have been encountered [10]. These issues play a significant role in acquainting a side effect of VR technology known as motion sickness [11] that limits the interaction of VR systems. In the VR industry, motion sickness is a well-known problem that creates a barrier in the full adaptation of this fascinating technology [7], [11]. Motion sickness leads to nauseous feeling, dizziness, vomiting and cold sweats [10] and can be dangerous in certain conditions [12], such as disorientation and vertigo. A report from the U.S. National Library of Medicine claims that one out of three individuals is predisposed to motion sickness and the impetus remains unknown [13]. Even though VR offers increased benefits and significantly decreased cost, a large number of users are unable to benefit from this technology due to the side effects of motion sickness [14].

Since the concerns regarding safety of VR users are highlighted often [15], researchers have made several contributions in identifying and reducing the cause and effect of motion sickness in VR systems. To analyze the impact of motion sickness in VR systems, previous studies have considered multiple factors of motion sickness individually. Factors include but not limited to gender [16], experience with VR [7] and type of virtual environments [17]. In addition, a few researchers [18]–[20] have also contemplated physiological factors such as heart rate [18], [19] and blood pressure [20] and subsequently reported the association of these factors with the motion sickness induced by VR systems. However, common in most VR users, the side effects of motion sickness vary from person to person. It is difficult to pin down the exact aspects of immersion which cause the agitation in human cognition [21]. Moreover, the combined impact of all the aforementioned factors in a single study is not yet present. Therefore, there is no consensus among researchers regarding the factors and side effects of motion sickness caused by VR systems. Thus, the varying views motivated us to investigate the collective impact of the factors associated with motion sickness and analyzing its impact on the physiological factors. Through an investigation of above mentioned factors, we aim to find the relationship of VR induced motion sickness with the human physiological factors. Our empirical experiment tends to help the VR community to lessen the side effects and increase the adaptation of VR systems.

A. CONTRIBUTION

This study reports several contributions that are listed as follows:

- A conceptual framework for motion sickness is proposed for the collective analysis of different factors associated with motion sickness.
- The value of nausea and oculomotor is analyzed subjectively and value of motion sickness in VR users is reported.
- This study reports significant differences in the levels of motion sickness in a different genre of environments.
- This study uncovers some exciting facts on the blood pressure, sugar level and heart rate of the VR users.
- The substantial differences in the amount of blood pressure, sugar level and heart rate of participants in a different genre of virtual environments are detailed.

B. STRUCTURE

This article will continue with a review of the background and related work in section II. Moreover, in section III the article follows a description of our proposed conceptual framework and hypothesis development. Section IV holds a brief description of research methodology, including virtual environment design, experiment design, system hardware, data collection instrument, data collection procedure and information about the participants. Section V is enriched with results and discourses. Lastly, the article is concluded in section VI.

II. BACKGROUND AND RELATED WORK

With the advent of VR systems, motion sickness has been observed as a common side-effect of using respective systems. Since VR has become a cheaper and widely disseminated technology, the motion sickness induced by VR systems has become one of the relevant issues. Therefore, in recent decades, a lot of research has been conducted in order to reduce the effects of motion sickness in VR. Researches indicate that multiple factors are held responsible for inducing motion sickness in VR systems. Recent studies [7], [16], [22]–[28] have exposed multiple factors associated with motion sickness induced by VR systems. These factors include but are not limited to: gender differences, virtual environment genre, VR experiences, graphical properties, virtual environment illuminance and motion sickness experiences. Moreover, the impact of motion sickness with the association of the aforementioned factors on the human physiological factors such as heart rate, blood pressure and sugar level were also reported [7], [19], [20].

To measure the impact of motion sickness on human corporal factors under different virtual environment conditions, it is necessary to understand the relationship of different factors with VR induced motion sickness. A brief introduction of different factors associated with motion sickness and their relationship with VR is described next.

A. GENDER

Individual differences such as gender is an important variable associated with the emergence of motion sickness in VR systems [29]. A few researchers have used the metrics of nausea and oculomotor to assess the motion sickness scores in gender difference [7], [16], [23]. Their findings set forth that women are comparatively more prone to motion sickness than men. In another work, the researchers experimented on a set of 40 participants to analyze the amount of motion sickness in VR users [30]. The result of the study indicates significant differences of motion sickness scores between male and female VR participants. Another research was conducted to investigate the amount of motion sickness considering different level of interaction in two VR games [16]. The researchers examined gender as an independent variable, and their study reports higher sickness rates for females in both VR games. In line with the previous work, it is evident that gender is an important variable and holds significant association with motion sickness. Moreover, it is important to consider gender as an independent variable while accessing the impact of motion sickness in VR content.

B. VIRTUAL ENVIRONMENTS

With the recent advancements in VR technology, various studies [26]–[28] have been conducted that report the side effects of VR due to a particular genre of the virtual environment. Researchers in [26] conducted a study to measure the visual fatigue in VR systems. Their research concludes that while experiencing VR content, motion sickness can be induced due to physical motion and virtual environment properties. The type of virtual content and the movement of objects in the virtual environment can also result in diminished motion sickness termed as Visually Induced Motion Sickness (VIMS). Even in the limited physical motion, VIMS lead to the illusory self-motion, which is accompanied to the straggling of physical signals with cerebral signals. Furthermore, the virtual environment illuminance is another factor that affects the amount of VIMS. It is reported that dark rooms can be more stressing than the brighter ones and stress is a factor of motion sickness [25]. Similarly, bright rooms produce less amount of eye fatigue as compared to dark places hence limiting VIMS.

Likewise, a virtual driving simulator was used to analyze the amount of motion sickness in VR users [28]. The participants of the study were exposed to a different level of illuminance in virtual driving simulator. Then their motion sickness scores were recorded subjectively. Results indicate that darker environments tend to produce high scores for motion sickness. Besides, another study conducted to analyze the impact of motion sickness in a virtual day and night simulator [31]. The participants were exposed to virtual contrasting simulators. The results of the study suggested different levels of motion sickness due to variability in virtual environment illuminance. However, their study only comprised ten male participants.

Another important aspect that must be considered while accessing the motion sickness in VR systems, is the graphical detail of the virtual environment [32]. An experiment was conducted on a set of 25 participants to examine association of graphical details with motion sickness [32]. The participants in the experiment were mainly divided into two groups. Each group came across graphically different virtual environments. One group was exposed to virtual environment built with exquisite details, and the other group came across the virtual environment comprising of low graphical information. Their research aimed to identify how graphical properties of virtual environments affect the amount of motion sickness in VR users. Interestingly, the difference in motion sickness scores reported between the low level and highly detailed virtual environments were not significant.

From the discussion above, it can be inferred that different genres of virtual environments with different themes have significantly different impact on the user's levels of motion sickness and must be considered in a single study. Moreover, the graphical differences in virtual environment prove that it is highly related to motion sickness that how much a person feels his or her presence in the VR environment [24].

C. FORMER EXPERIENCE

With the rising trend of VR, it was observed that past experience with 3D content and VR also holds an important relationship with motion sickness [23], [30], [33]. To analyze the association of motion sickness with former experience, an experiment was conducted by introducing overwritten symbols in VR environments [30]. For this purpose, a total of 40 participants were selected who prior experienced motion sickness of any type. Their research reported the motion sickness variation due to individual differences and previous experience with motion sickness. It was considered as an essential variable to analyze the impact of motion sickness in VR systems properly. Nonetheless, another similar study was also conducted to analyze the causes of motion sickness in VR systems [23]. The results show that experience with VR has a relationship with motion sickness. There is a probability that the contemporary users of VR technology are more likely to suffer the side effects of motion sickness.

Correspondingly, an experiment was conducted where participants experienced two different virtual environments to analyze the impact of motion sickness in VR content [33]. Both virtual environments differ in the properties of the 3D objects. The focus of one virtual environment was on the near plane objects, and the other virtual environment focused on the far plane objects. Initially, their research included 34 volunteer participants. However, after analyzing the demographics, 14 participants were removed from the experiment as they had experience with VR content. Moreover, the motion sickness of the participants was recorded subjectively. The results of their study report different levels of motion sickness in different virtual environments. Though their data reports several facts, yet it would be interesting to evaluate the sickness scores with users having VR experience against the users with no VR experience.

In line with the previous work, it is evident that VR experience and motion sickness experience has a relationship with initiating motion sickness in VR systems. Moreover, the severity of motion sickness can be dangerous, and novice users must make their physical assessments before diving into the VR experience [25].

D. HUMAN CORPOREAL FACTORS

With the discomforts introduced by motion sickness in VR, several studies have been conducted to identify the impact of motion sickness on human corporeal or physiological factors. Different studies [7], [15], [18]–[20], [23] have reported variation in human physiological factors such as (Heart Rate, Blood Sugar and Blood Pressure) due to motion sickness. An experiment was performed on a set of 46 participants to analyze the impact of motion sickness on human physiological variables [34]. The participants were set forth with static and dynamic graphics experienced by participants through VR headset. The results report variability in the participant's heart rate after the exposure to VR content.

Likewise, experiments were conducted to analyze the impact of motion sickness subjectively and objectively [35]. For the purpose, 20 participants were exposed to virtual dynamic 3D content and variations in human physiological factors were recorded objectively. The results of the experiments report variability in heart rate due to exposure of virtually dynamic 3D content. Moreover, the results also suggest considering heart rate as an essential human physiological variable when analyzing motion sickness in VR system.

Lately, the authors of [24] in their research conducted an experiment to measure the heart rate variability of VR users when exposed to VR content. The experiment was performed on a set of 14 VR users, and the results reported high fluctuations in heart rate variability during all the recording phases. Additionally, previous studies [18], [19] also reported that the variation in heart rate is associated with motion sickness. The report of their experiments suggests that the heart rate increases significantly, in result amplifying motion sickness. Besides the direct relationship of heart rate with motion sickness, fear and blood pressure also have a relationship with heart rate variability [20]. Moreover, the results of the study [20] show the rise and fall of blood pressure and heart rate altogether when feeling danger or facing any fear. Furthermore, the authors of [36] in their research performed experiments on a set of users considering physiological factors heart rate, blood pressure, anxiety and depression. From the results, it was observed that heart rate and blood pressure are dynamic markers that can change drastically in response to various emotional or physical stimuli. Hence, the relationship between blood pressure, heart rate and fear have a strong association with motion sickness.

In continuation, the variation in blood sugar level of VR users is also considered as a crucial variable in different studies [15], [23]. Some of the symptoms that are closely associated with motion sickness include blurred vision, dizziness and vertigo [7]. These symptoms also have a close association with the human physiological factors. The authors of [7], [15], [23] report that while experiencing VR contents, a variation in sugar level of VR users can be seen due to the change in the levels of dizziness, blurred vision and vertigo. Hence, the symptoms of motion sickness show a strong association with the blood sugar level of VR users.

Moreover, an experiment was performed to identify different levels of motion sickness under different virtual environment properties [27]. For the purpose, a VR simulator having multiple objects settings was used. The objects settings included virtual player height adjustment, angle of view and virtual movement speed variations. In VR content, these settings have a strong relationship with human physiological factors, and there is a need to include aforementioned settings when analyzing the impact of motion sickness in VR users. Besides, a similar study was conducted with the addition of another corresponding VR simulator [17]. Reportedly, a subjective and objective evaluation was drawn, and the participants experienced both VR simulators and showed intense levels of nausea. Both VR simulators included motion graphics, but these studies were limited to the VR environments of the same genre. Also, there were no significant differences in the VR simulators used for the study.

E. MOTION SICKNESS APPRAISAL

To analyze the amount of motion sickness in VR users, different studies [7], [10], [17], [23], [37] have used the Simulator Sickness Questionnaire (SSQ) as a subjective measurement tool for motion sickness. SSQ is a 16-item questionnaire that provides computer or manual scoring for subjective analysis of motion sickness in VR users [37]. The 16 items presented in SSQ are closely related to motion sickness. Additionally, these 16 items are categorized under two main components, i.e. nausea and oculomotor [10], [15], [23], [37].

In order to deeply analyze the impact of motion sickness in VR technology, there is a prior need to access all the factors mentioned above in different genre of virtual environments. That include different themes, gender differences, experiences with VR and 3D games along with the physiological factors such as (Heart rate, Sugar level and Blood pressure) and report the results accordingly. Hence, the obtained results might lead to exposing how the physiological factors of VR users are deeply affected by motion sickness.

III. FRAMEWORK AND HYPOTHESIS DEVELOPMENT

It is evident from the literature that motion sickness in VR systems can be articulated through various factors and the combined effect of these factors need to be evaluated. For the purpose, a framework is conceptualized, as shown in Fig 1. An insight is presented by considering virtual environments for VR users to interact and analyse the impact of VR induced motion sickness with human response and physiological factors. Here, the motion sickness is a subjective measure that

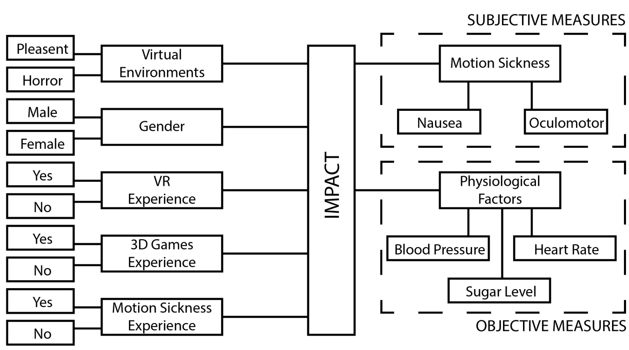

FIGURE 1. Conceptual framework for motion sickness.

is based on nausea and oculomotor, whereas, physiological body conditions is an objective measure that is based on blood pressure, heart rate and sugar level. These factors need to be used for the empirical motion sickness in the evaluation process of VR system. In this study, the proposed conceptual framework assists the researcher in the development of hypothesis to proceed further.

To empirically evaluate the proposed conceptual framework for motion sickness, six different hypotheses are developed as follows:

- $H1$ VR users will feel less motion sickness while experiencing pleasant environment than a horror environment.
- $H2$ Male VR users will suffer less motion sickness as compared to female VR users while experiencing pleasant environment or a horror environment.
- $H3$ VR users having VR experience or 3D game experience or motion sickness experience will undergo less motion sickness while experiencing pleasant environment than a horror environment.

As we were also interested in measuring the impact of virtual environments on the physical body changes, i.e. Heart Rate (HR), Blood Pressure (BP) and Sugar Level (SL) of the VR users, we further formulated our hypothesis as follows:

- $H4$ VR users' BP increase while experiencing horror environment in contrast to the pleasant environment.
- $H5$ VR users' have increased HR while experiencing horror environment than a pleasant environment.
- $H6$ The SL of VR users decrease while experiencing horror environment than a pleasant environment.

After formalizing the hypothesis, two VR environments of different genre were designed and developed to evaluate the conceptual framework.

IV. RESEARCH METHODOLOGY

Following the proposed conceptual framework, two different genres of virtual environments, i.e. Horror and Pleasant virtual environment genre, were designed. Both the virtual environments had different graphical properties to analyse the difference in the amount of motion sickness induced by each virtual environment. The details of the virtual environment designs are given in the next subsection.

A. VIRTUAL ENVIRONMENT DESIGN

The pleasant genre environment (VE1) comprises of an outdoor scene with daylight illuminance, as shown in Fig. 2.

FIGURE 2. An image of pleasant genre virtual environment.

The scene begins with a hut at the corner of a shore. The green foliage and fluttering butterflies add peaceful ambience to the graphical. It also enables the user to roam around and within the hut. Warmth of hut is represented through the color scheme and graphics of a fireplace that overall compliments the pleasing environment. Furthermore, the user can also witness a noisy ship sailing across the sea and chirping birds flying high in the sky. This was done in order to enhance the immersion. To limit the roam area in VE1, a boundary was placed by making use of fences. Hence, the user was able to move freely within the playable area.

Whereas, the horror genre (VE2) of the virtual environment is an indoor scene. It starts off from a morgue in an abandoned hospital and continues as the user move around the hospital. The spine-chilling visuals of blood strains, broken windows, upside down stretchers create a horrific environment. To add to the creepiness, flickering lights and shrilled screams of children and women plays an important role to induce fear. The user can also move to alternate floors of the hospital since the morgue is situated in the basement. Moreover, to limit the user playable area, a boundary was set using barren walls and misty windows of the hospital. An image of VE2 is shown in Fig. 3.

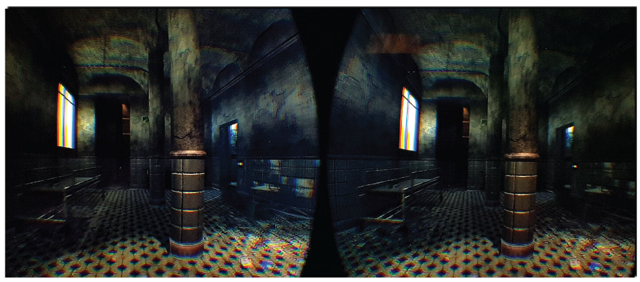

FIGURE 3. An image of horror genre virtual environment.

B. EXPERIMENT DESIGN

The experiment is designed to investigate the impact of VE1 and VE2 on the user's physiological factors. To assess how the participants respond with different genre conditions, a within-group design is used. Overall, the experiment was performed in a controlled environment with appropriate space and luminance, under the supervision of a trained medical expert and an ambulance was on standby. Fig. 4 illustrates the experimental setups used in this research.

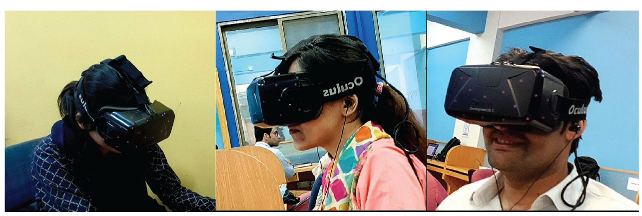

FIGURE 4. Participant experiencing virtual environment and objective measures are being recorded.

C. SYSTEM HARDWARE

For the proper tracking of the participant's head movement, motion tracker was placed in front of the participant's seat. To run the virtual environments, a commercially available HMD named Oculus Rift DK2 was used. Oculus Rift DK2 has two lenses, one for each eye that helps the users with complete immersion. Each lens had a resolution of 2402 × 1461 pixels with a field-of-view of 106.093. The HMD was connected to a computer having Intel Eeon E2630v4 10 core 3.1GHz turbo boost processor, 12 GB NVIDIA TitanX Pascal GPU and 128 GB of DDR4 RAM. Moreover, the system was connected to a 3D noise-cancelling audio headset to diminish surrounding sounds in order to increase the immersion of the user in the VR environment.

D. DATA COLLECTION INSTRUMENT

In data collection, many response variables were considered, including subjective and objective measures. Detail of subjective and objective measurements is given in the following subsections.

1) SUBJECTIVE MEASUREMENT

For subjective measurements, motion sickness of the participants was measured using SSQ for both virtual environments. The symptoms of motion sickness reported in SSQ were recorded against well-defined sixteen symptoms which are categorised as Nausea (N) and Oculomotor (O) [23]. The participants reported the severity of these symptoms using a recommended 4-point Likert scale. Total Motion Sickness (TMS) was then calculated by adding the sickness scores of N and O in each participant as also done in many other studies [10], [23], [37].

2) OBJECTIVE MEASUREMENT

For the objective measurement, participant's BP, SL and HR were measured. The equipment used to record objective measurements are listed in Table 1. The BP of participants was divided into five categories [38]: 1) normal, 2) elevated, 3) hypertension (stage 1), 4) hypertension (stage 2) and 5) hypertensive crisis, as shown in Fig. 5. The (systolic) upper value first, followed by (diastolic) lower value was measured in units of millimeters of mercury (mmHg). HR was measured as the number of beats per minute (bpm). The SL of each participant was measured in terms of milligrams per deciliter (mg/dL).

TABLE 1. Instruments used for recording the BP, HR and SL of participants along with the units of measurement.

Instrument	Purpose	Unit
SANITAS SBM 52	BP Measurement	mmHg
SANITAS SBM 52	HR Measurement	bpm
ACCU-CHEK Performa	SL Measurement	mg/dL

LEVEL	BLOOD PRESSURE CATEGORY	SYSTOLIC (mmHg)		DIASTOLIC (mmHg)
1	NORMAL	LESS THAN 120	and	LESS THAN 80
2	ELEVATED	120-129	and	LESS THAN 80
3	(HYPERTENSION) STAGE 1	130-139	or	80-89
4	(HYPERTENSION) STAGE 2	140 OR 140+	or	90 OR 90+
5	HYPERTENSIVE CRISIS	180+	and/or	120+

FIGURE 5. BP categories for healthy adults ranging from normal to hypertensive crisis.

E. DATA COLLECTION PROCEDURE

A day before the experimentation, a consent form approved by the ethics committee of COMSATS University Islamabad was filled by all participants. Before starting the experiment, the participants were requested to read instructions to understand their tasks. After reading the instructions, participants were facilitated with further clarifications if required. Furthermore, the participants were asked to fill in their demographic's information. In continuation, BP, HR and SL of each participant were recorded before the start of phase 1 of experiments. SANITAS SBM 52 was attached on the left linker arm of the participant to record BP and HR before exposing them to VE1. To record the SL of participants, ACCU-CHEK Performa was used. Each objective measure was recorded four times. Initially, objective measurements of each participant were recorded prior to experiencing any virtual environment. Afterwards, the objective measurements were re-recorded once the participants had successfully finished experiencing VE1 and VE2, respectively. The experiment was divided into two phases, as illustrated in Fig. 6. Following is the description of our experiment phases:

1) EXPERIMENT PHASE 1

In the first phase of the experiment, the participants were introduced with one of the two virtual environments. HMD was set on the head of participants after recording the initial objective measurements. The participants were allowed to roam freely in the virtual environment for as long as they desire. The virtual navigation of participants was also monitored by the researchers on the 15'' LCD screen. Once the participants finished experiencing the virtual environment, the HMD was removed from the participants head. Again, objective measurements of each participant were measured and recorded. In last, the participants were provided SSQ to fill-in, based on their experience. To avoid any effect and learning of virtual environments in results, participants were allowed to take rest for two days before starting phase 2 of the experiment.

2) EXPERIMENT PHASE 2

The participants who completed phase 1 were introduced with phase 2 of the experiments. The participants BP, HR and SL were measured again before exposing them to virtual environments. Once the physiological measurements of

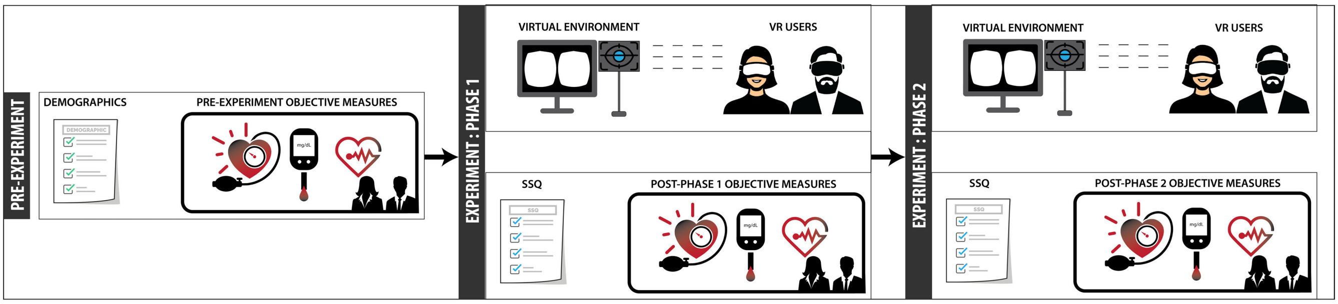

FIGURE 6. Experiment process flow explaining the two phases and the collection of data subjectively and objectively.

participants were recorded, HMD was again mounted on their heads of the same set of participants. The participants in phase 2 were exposed to another virtual environment than they experienced in phase 1. After the participants finished experiencing the virtual environment, the HMD was turned off and removed from the participants head. The objective measurements of the participant were measured and re-recorded. At last, for subjective analysis, participants were again provided with SSQ to fill-in.

F. PARTICIPANTS

A total of 51 healthy participants (23 female users and 28 male users, aged 18-28 years) voluntarily participated in this study. The participants were advised to avoid all food, caffeine-containing beverages, and smoking for 2 hours and alcohol and medication for 24 hours before each phase of the experiment. The participants were informed that they would be taking part in an experiment that measures motion sickness while experiencing different VR environments. As mentioned earlier, before starting the experiment, initial measurements were recorded. It shows that 58.8% of participants did not have any VR experience. Also, a total of 70.6% of participants had the experience of 3D games. Furthermore, 35.3% of participants had prior experience with motion sickness.

V. RESULTS AND DISCUSSION

The obtained data was transformed from the questionnaire and physical measurements to the SPSS tool for statistical analysis. In total, 5 out of 51 participants discontinued after phase 1 due to severe symptoms of motion sickness. Out of these 5 participants, 4 were females, and 1 was male. Among those the BP of participant no.18 and participant no.23 increased from normal to hypertension stage1 category after experiencing phase 1 of the experiments. In total, 46 participants were able to complete the rest of the experiments successfully. The descriptive statistical analysis was used to measure the physiological body conditions (i.e. objective measure) before and after experiencing phase1 and phase2 of the experiments. The statistics show that BP, HR and SL for $N = 46$ participants was normally distributed, with skewness of ± 1.05 and kurtosis of ± 1.95, as shown in Table 2 and Table 3.

TABLE 2. Descriptive statistics of heart rate, blood pressure and sugar level in pre-phase1 and post-phase1 VR experience.

Factors	Pre-Phase1				Post-Phase1			
	Mean	SD	Skewness	Kurtosis	Mean	SD	Skewness	Kurtosis
Blood Pressure (n=46)	1.58	0.85	0.93	-0.98	1.86	1.04	0.63	-1.14
Heart Rate (n=46)	79.39	12.03	0.34	-0.94	83.65	13.20	0.50	-0.48
Sugar Level (n=46)	114.10	17.29	0.18	-0.99	118.71	19.40	0.12	-1.10

TABLE 3. Descriptive statistics of heart rate, blood pressure and sugar level in pre-phase2 and post-phase2 VR experience.

Factors	Pre-Phase2				Post-Phase2			
	Mean	SD	Skewness	Kurtosis	Mean	SD	Skewness	Kurtosis
Blood Pressure (n=46)	1.54	0.78	1.02	-0.54	2.50	0.93	-0.67	-0.80
Heart Rate (n=46)	77.41	9.67	0.65	0.18	91.86	17.25	-0.02	-0.25
Sugar Level (n=46)	114.91	16.92	0.14	-1.02	104.21	13.86	1.05	1.95

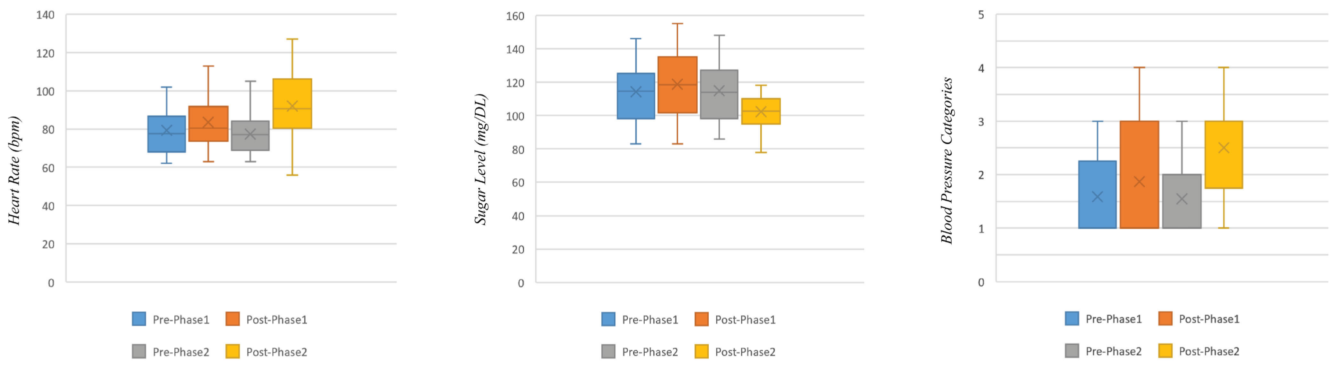

FIGURE 7. Box and whisker plots illustrating the pre and post effect of VR content on the physiological factors of participants.

Overall, it is observed that participants have a normal level of BP, HR and SL before phase 1 and phase 2. The findings suggest, a slight change in BP, HR and SL of participants after phase 1. However, the findings highlight more increase in BP and HR and reduction in SL of participants after phase 2. The overall observations made before and after experiencing experimental conditions using box-and-whisker plot is presented in Fig. 7.

Furthermore, the descriptive statistical analysis is used to measure the motion sickness (i.e. subjective measure) after experiencing phase1 and phase2 of the experiments. Fig. 8 shows the mean scores of motion sickness for N, O and TMS in VE1 and VE2. It is evident that N, O and TMS are higher in VE2 than in VE1. Fig. 9, represents the mean scores of N and O for male and female participants. The findings suggest that N and O are higher of females than male participants.

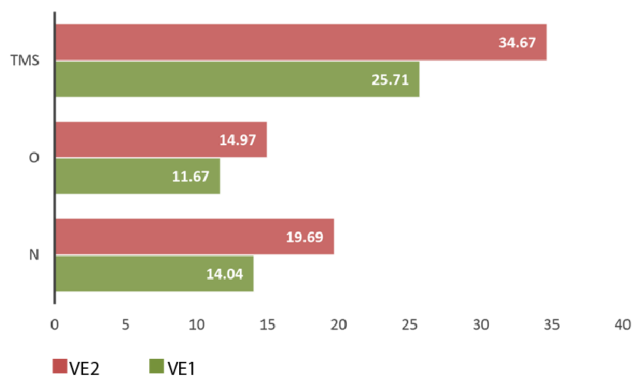

FIGURE 8. Sickness scores for N, O and TMS in VE1 and VE2.

A. STATISTICAL INTERPRETATION AND HYPOTHESIS TESTING

To verify the difference in the amount of motion sickness in different VR environment genre, paired-sample t-test were applied. Moreover, within-subjects Analysis of Variance (ANOVA) was conducted to statistically evaluate the impact

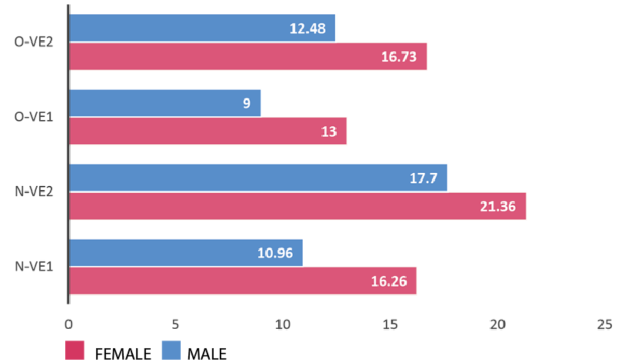

FIGURE 9. Mean sickness scores for N and O in male and female VR users in two different virtual environments.

of motion sickness in different genre of virtual environments with gender, VR experience, 3D game experience, motion sickness experience, BP, HR and SL. The same analysis approach has been adopted by various studies for similar type of data [39]. With the intention of confronting where the difference resided in dependent variables across distinctive independent variables and their conditions, the analysis would continue with further tests in this section.

H1: VR users will feel less motion sickness while experiencing pleasant environment than a horror environment.

The results of paired samples t-tests showed comparisons between N, O and TMS individually, experienced by participants in the two phases of experiments, as shown in Table 4. The t-test showed that, there was a significant increase in the levels of N in VE2 ($M = 19.69$, $SD = 4.59$); $t(45) = 14.02$, $p = 0.00$ as compared to the level of N in VE1 ($M = 14.04$, $SD = 3.70$). Also, t-test indicated that, there was a significant increase in the levels of O in VE2 ($M = 14.97$, $SD = 3.32$); $t(45) = 9.55$, $p = 0.00$ as compared to levels of O in VE1 ($M = 11.67$, $SD = 2.21$). Moreover, t-test indicated that, there was a significant increase in the scores of TMS in VE2 ($M = 34.67$, $SD = 7.35$); $t(45) = 14.74$, $p = 0.00$ as compared to TMS in VE1 ($M = 25.71$, $SD = 5.32$), hence **H1 is accepted**. Overall, t-test results suggest that the value of N,

TABLE 4. T-Test of Nausea, Oculomotor and Total Motion Sickness between VE1 and VE2.

Factors	Environments	Mean	SD	t-test	df	p-value
Nausea	VE1	14.04	3.70	14.02	45	0.00
	VE2	19.69	4.59			
Oculomotor	VE1	11.67	2.21	9.55	45	0.00
	VE2	14.97	3.32			
Total Motion Sicness	VE1	25.71	5.32	14.74	45	0.00
	VE2	34.67	7.35			

O and TMS is significantly higher in horror environment than in a pleasant environment.

H2: Male VR users will suffer less motion sickness as compared to female VR users while experiencing pleasant environment or a horror environment.

The results of two-way crossed factor ANOVA with a Greenhouse-Geisser correction showed that TMS was higher in females, as shown in Table 5. The results showed that mean scores of N ($F(1.50, 66.30) = 9.93$, $p = 0.001$) and O ($F(1.00, 44.00) = 8.86$, $p = 0.001$) in VE1 and VE2 is statistically significantly different with respect to gender. Post hoc test showed that with respect to VE1, N in females ($M = 16.26$, $SE = 0.70$) is significantly higher than N in males ($M = 10.96$, $SE = 0.58$). Moreover, our results also prove that with respect to VE2, N in females ($M = 21.36$, $SE = 1.15$) is significantly higher as compared to N in males ($M = 17.70$, $SE = 0.97$). Furthermore, O in VE1 and VE2 was also significantly higher in females. For VE1, O in females ($M = 13.0$, $SE = 0.51$) was higher as compared to O in males ($M = 9.0$, $SE = 0.43$). For VE2, the amount of O in females ($M = 16.73$, $SE = 0.78$) was higher as compared to the amount of O in males ($M = 12.48$, $SE = 0.65$), hence TMS was higher in females which indicates **H2 is accepted**.

H3: VR users having VR experience or 3D game experience or motion sickness experience will undergo less motion sickness while experiencing pleasant environment than a horror environment.

While individually analyzing the impact of VR experience, it has been observed that 3D game experience and motion sickness experience on pleasant environment or horror environment is not significantly different ($p>0.05$). Therefore, **H3 is rejected**.

H4: VR users' BP increase while experiencing horror environment in contrast to the pleasant environment.

The results of repeated measure ANOVA with a Sphericity correction showed that virtual environment does influence the BP, as shown in Table 6. The mean BP in pre and post-experience of virtual environments differed statistically significantly in gender ($F(2, 88) = 14.503$, $p = 0.00$). Three, paired samples t-tests were applied to make post hoc comparisons between VE1 and VE2. First, paired samples t-test indicated that there was a significant increase in the BP of participants after experiencing VE1 ($M = 1.86$, $SD = 1.04$) as compared to pre-experience ($M = 1.58$, $SD = 0.85$) with VE1 conditions; $t(45) = -2.78$, $p = 0.008$. A second, paired samples t-test indicated that there was a significant increase in the BP of participants after experiencing VE2 ($M = 2.50$, $SD = 0.93$) as compared to pre-experience ($M = 1.54$, $SD = 0.78$) with VE2 conditions; $t(45) = -5.78$, $p = 0.00$. A third, paired samples t-test indicated that there was a significant increase in the BP of participants after experiencing VE2 ($M = 2.50$, $SD = 0.93$) as compared with the post-experience of VE1 ($M = 1.86$, $SD = 1.04$) conditions; $t(45) = -3.80$, $p = 0.00$. These results suggest that the type of virtual environment does influence the BP of VR user that **accepts H4**. Specifically, our results suggest that when participants are exposed to VE1 and VE2, the BP of participants increases as compared to pre-experience of virtual environments.

H5. VR users' have increased HR while experiencing horror environment than a pleasant environment.

A repeated measures ANOVA with Greenhouse-Geisser correction compares the impact of motion sickness on the HR in different gender of participants ($F(1.42, 62.46) = 5.71$, $p = 0.011$), as shown in Table 7. Three, paired samples t-tests were used to make post hoc comparisons between conditions. A first paired samples t-test indicated that there was a significant increase in the scores of HR for VE1 ($M = 83.65$, $SD = 13.20$) as compared to pre-experience ($M = 79.39$, $SD = 12.03$) with VE1 conditions; $t(45) = -3.51$, $p = 0.001$. A second paired samples t-test indicated that there was a significant increase in the scores of HR for VE1 ($M = 83.65$, $SD = 13.20$) as compared VE2 ($M = 91.86$, $SD = 17.25$) conditions; $t(45) = 6.18$, $p = 0.00$. A third paired samples t-test indicated that there was a significant increase in the scores for VE2 ($M = 91.86$, $SD = 17.25$) as compared to pre-experience ($M = 77.41$, $SD = 9.67$) with VE2 conditions; $t(45) = 6.165$, $p = 0.00$. These results suggest that the type of virtual environment does influence the HR of VR users. Our results specifically suggest that when participants are exposed to VE1 and VE2, the HR of participants increases statistically significant as compared to pre-experience with virtual environments. Therefore, **accepts H5**.

H6. The SL of VR users decrease while experiencing horror environment than a pleasant environment.

TABLE 5. Results of cross factor ANOVA for Nausea and Oculomotor on gender difference between VE1 and VE2.

Factors	Environments *Gender	Mean	SE	F	df	p-value
Nausea	VE1*Male	10.96	0.58	9.93	(1.50, 66.30)	0.001
	VE1*Female	16.26	0.70			
	VE2*Male	17.70	0.97			
	VE2*Female	21.36	1.15			
Oculomotor	VE1*Male	09.00	0.43	16.62	(1.56, 68.84)	0.000
	VE1*Female	13.00	0.51			
	VE2*Male	12.48	0.65			
	VE2*Female	16.73	0.78			

TABLE 6. T-test of BP between Pre-VE1 and Post-VE1, pre-VE2 and Post-VE2, and Post-VE1 and Post-VE2.

Factors	Environments	Mean	SD	t-test	df	p-value
BP	Pre-VE1	1.58	0.85	-2.78	45	0.008
	Post-VE1	1.86	1.04			
	Pre-VE2	1.54	0.78	-5.78	45	0.000
	Post-VE2	2.50	0.93			
	Post-VE1	1.86	1.04	-3.80	45	0.000
	Post-VE2	2.50	0.93			

TABLE 7. T-test of HR between Pre-VE1 and Post-VE1, pre-VE2 and Post-VE2, and Post-VE1 and Post-VE2.

Factors	Environments	Mean	SD	t-test	df	p-value
HR	Pre-VE1	79.39	12.03	-3.51	45	0.001
	Post-VE1	83.65	13.20			
	Pre-VE2	77.41	9.67	6.16	45	0.000
	Post-VE2	91.86	17.25			
	Post-VE1	83.65	13.20	6.18	45	0.000
	Post-VE2	91.86	17.25			

TABLE 8. T-test of SL between Pre-VE1 and Post-VE1, pre-VE2 and Post-VE2, and Post-VE1 and Post-VE2.

Factors	Environments	Mean	SD	t-test	df	p-value
SL	Pre-VE1	114.10	17.29	-2.42	45	0.019
	Post-VE1	118.71	19.40			
	Pre-VE2	114.91	16.92	4.73	45	0.000
	Post-VE2	104.21	13.86			
	Post-VE1	118.71	19.40	5.83	45	0.000
	Post-VE2	104.21	13.86			

Subsequently, a repeated measures ANOVA with Sphericity correction showed the impact of motion sickness on the SL in gender ($F(2, 88) = 2.382$, $p = 0.09$) as shown in Table 8. Three, paired samples t-tests were used to make post hoc comparisons between conditions. A first paired samples t-test indicated that there was a significant increase in SL of participants experiencing VE1 (M = 118.71, SD = 19.40) as compared to pre-experience (M = 114.10, SD = 17.29) with VE1 conditions; $t(45) = -2.426$, $p = 0.019$. A second paired samples t-test indicated that there was a significant decrease in SL of participants after experiencing VE2 (M = 104.21, SD = 13.86) as compared to pre-experience (M = 114.91, SD = 16.92) with VE2 conditions; $t(45) = 4.731$, $p = 0.00$. A third paired samples t-test indicated that there was significant decrease in the SL of participants experiencing VE2 (M = 104.21, SD = 13.86) as compared to VE1 (M = 118.71, SD = 19.40) conditions; $t(45) = 5.831$, $p = 0.00$. These results suggest that the type of virtual environment does influence the SL of VR users. Specifically, our results suggest that SL of VR users increase when exposed to the VE1. The SL of VR users decrease significantly after experiencing horror environments. Hence, **accept H6**.

Furthermore, a repeated measures ANOVA with Greenhouse-Geisser correction showed the participants past experience with VR (VRXP) on the BP in pre and post VR experience conditions ($F(1.58, 69.51) = 1.769$, $p = 0.18$). Based on our results, there was no statistically significant difference ($p>0.05$). These results suggest that past experience with VR does not have any effect on BP of participants. Another repeated measures ANOVA with Greenhouse-Geisser correction was conducted to analyze the impact of participants VRXP on the HR in pre and post VR experience conditions ($F(1.41, 62.13) = 5.63$, $p = 0.012$). Our post hoc results prove that the participants who had no experience with VR had a higher HR after experiencing VE2 (M = 95.40, SE = 3.40) as compared to VE1 (M = 84.12, SE = 2.66) and pre-experience (M = 78.44, SE = 2.42) with virtual environment. For the participants that had prior experience with VR, the HR was significantly higher in post-experience of VE2 (M = 87.66, SE = 3.71) as compared to post-experience with VE1 (M = 83.09, SE = 2.91) and pre-experience (M = 80.52, SE = 2.64) with virtual environment. Specifically, our results suggest that the HR of participants with no VRXP increase statistically significantly as compared to participants with VRXP when exposed to the horror genre of environments. However, there was no significant difference observed for the participants with and without VRXP in pleasant environment. Another repeated measures ANOVA with Greenhouse-Geisser correction was conducted to analyze the impact of participants VRXP on the SL in pre and post VR experience conditions ($F(1.72, 76.08) = 2.48$, $p = 0.097$). Our results show that there is no significant difference in the SL of participants with respect to VRXP in different virtual environment.

Furthermore, a repeated measures ANOVA with Greenhouse-Geisser correction was conducted to analyse the impact of past-experience with 3D games (3DGXP) on the BP, SL and HR of participants in pre and post VR experience conditions. For BP ($F(1.62, 71.26) = 2.697$, $p = 0.085$), SL ($F(1.71, 75.52) = 3.13$, $p = 0.057$) and HR ($F(1.38, 60.83) = 1.55$, $p = 0.22$), there was no statistical significant difference ($p>0.05$) in pre and post-experience with virtual environments. Specifically, our results prove that 3DGXP does not significantly impact the BP, SL and HR of VR users.

Moreover, a repeated measures ANOVA with Greenhouse-Geisser correction was conducted to analyze the impact of past experience with motion sickness (PMS) on the BP and HR of participants in pre and post VR experience conditions. For BP ($F(1.56, 68.70) = 0.702$, $p = 0.465$) and HR ($F(1.36, 60.24) = 0.45$, $p = 0.566$), there was no statistical significant difference ($p>0.05$) in pre and post-experience with virtual environments. For analyzing the impact of PMS on SL of participants, repeated measures ANOVA with Sphericity correction was conducted ($F(2, 88) = 0.96$, $p = 0.383$) and no significant difference was observed. Our results prove that there is no effect of PMS on BP, HR and SL of VR users.

B. DISCUSSION

The empirical evaluation of experimental data denotes that motion sickness in VR is a complicated phenomenon. One of the main reasons is VR systems are versatile [40], and motion sickness is also complex syndrome [41]. Therefore, to investigate the relationship between motion sickness and VR, other than N and O, which are hallmark symptoms of motion sickness, we also consider other symptoms of motion sickness. It includes HR, BP and SL. Keeping in view, the subjective measures, from the results, it is evident that all the 46 participants show acute symptoms of motion sickness when exposed to the horror genre of environments. Furthermore, females show severe signs of motion sickness than males when exposed to horror VR environments as compared to pleasant VR environments.

Interestingly, it is observed that the objective measurements also indicate excruciating symptoms of motion sickness in females (BP and HR increase while SL decreases significantly) than males. The reason for this situation might be females ruminate sensations more than males. Therefore, they report greater fear than males [40], and fear is related to motion sickness.

In the past, a few studies show a relationship between HR and motion sickness. However, from the literature, it is not evident that HR and BP have significant co-relationship. Due to this, various medical doctors have a difference in opinion about the exact correspondence between HR and BP. However, it is true that BP and HR either escalate or plunge together [20] when you face danger or fear. It is also evident from our analysis, both BP and HR of all participants rise in horror VR environment. In this study, we also considered a change in SL as one of the symptoms of motion sickness in VR. One rationale for consideration of SL comes from the observation that change in SL is associated with dizziness, vertigo and blurred vision which are symptoms of motion sickness [15], [23]. Results indicate that our assumption is valid because, in the horror VR environment, TMS of participants increased while their SL decreased.

VR induced motion sickness is a common syndrome that occurs to some individuals upon experiencing VR. One of the

TABLE 9. Simulator sickness questionnaire. An enhanced method for quantifying simulator sickness.

Instructions : Circle how much each symptom below is affecting you right now.				
1. General Discomfort	None	Slight	Moderate	Severe
2. Fatigue	None	Slight	Moderate	Severe
3. Headache	None	Slight	Moderate	Severe
4. Eye strain	None	Slight	Moderate	Severe
5. Difficulty focusing	None	Slight	Moderate	Severe
6. Salivation increasing	None	Slight	Moderate	Severe
7. Sweating	None	Slight	Moderate	Severe
8. Nausea	None	Slight	Moderate	Severe
9. Difficulty concentrating	None	Slight	Moderate	Severe
10. «Fullness of the Head»	None	Slight	Moderate	Severe
11. Blurred Vision	None	Slight	Moderate	Severe
12. Dizziness with eyes open	None	Slight	Moderate	Severe
13. Dizziness with eyes closed	None	Slight	Moderate	Severe
14. *Vertigo	None	Slight	Moderate	Severe
15. **Stomach awareness	None	Slight	Moderate	Severe
16. Burping	None	Slight	Moderate	Severe

*Loss of orientation with respect to vertical upright.

**A feeling of discomfort which is just short of nausea.

ways to treat VR induced motion sickness is by taking drugs. However, many of these drugs have side effects e.g. occasionally disorientation, dry mouth and drowsiness. Instead of treatment, early self-diagnosis should be emphasized later on. Therefore, people should acknowledge the prevailing conditions and symptoms that may cause motion sickness while experiencing VR. Based on our results and findings, we aim to provide general guidelines about the circumstances that may lead to motion sickness in VR users. Below mentioned guidelines should direct individuals who intend to use VR to overcome any mishap.

1) *People suffering from low SL should not confront the horror genre.*
2) *Both VR experience and physical exertion increases heart rate. Therefore, one must not sustain VR immediately after any physical exertion and vice versa.*
3) *As observed, blood pressure increases irrespective of gender and genre; therefore, blood pressure patients need to be careful while experiencing VR.*
4) *There can be a significant change in HR, BP and SL while experiencing VR. Therefore, VR experience is not suitable for pregnant women and children as it may lead to motion sickness.*
5) *Fear factor restricts horror environment experience. One should only select a pleasant genre keeping in mind their respective phobias.*

VI. CONCLUSION AND FUTURE WORK

In literature, assumptions exist about the relationship of different physiological and subjective measures of motion sickness in virtual environments. However, no adequate empirical evidence exists to support this belief. Therefore, the lack of empirical investigation makes it difficult for researchers to state any relationship confidently. It gives us an opportunity to empirically identify the association of different physiological and subjective measures of motion sickness in virtual environments.

This study can be considered as the first attempt to understand and expand the body of knowledge in this field. Therefore, purposefully, like other studies of VR [42], a suite of virtual environments with distinct contexts, were created to spot any relationship. The scope of this research was limited to pleasant and horror environment genres. The choice of the selected genre was based on [25], i.e. using flamboyant imagery in day scene for a pleasant virtual environment whereas grotesque imagery for stressed and horror virtual environment.

Following the in-depth analysis, results indicate the presence of a significant relationship of different physiological and subjective measures of motion sickness in virtual environments. Meanwhile, several aspects need to be explored to identify the accurate association. Therefore, it opened new directions for researchers. In future, the parameter considered in this study can be applied on a different set and increased number of users to generalize our findings. Moreover, this research may be extended, considering the different genre of virtual environments as well as day and night settings of the same virtual environment.

Similarly, there is a probability that the change in details of virtual environments might affect the factors associated with motion sickness. Thus, resulting in an increase or decrease of motion sickness in VR users. Furthermore, dynamic 3D objects and multiple graphical factors with varying graphical properties dependent on changing VR content are also few of the blind spots that will be explored further in future.

APPENDIX

See Table 9.

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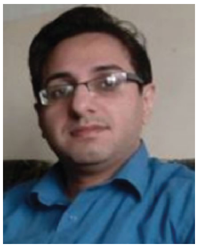

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