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Affects of Perceived-actions within Virtual Environments on User Behavior on the Outside

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***Abstract*—3D visualization has witnessed exponential growth driven by advances in computer-generated imagery that now include immersive technologies enabling first-person experiences with depth perception and spatial awareness. We investigated two popular uses of VR in 3D architectural visualization: a "passive walkthrough" vs. an "interactive walkthrough". We designed a within-subject experiment to measure the user-perceived quality and conduct a behavior analysis of users in both experiences. All participants (N=34) were exposed to both conditions and afterwards responded to a post-experience questionnaire. We recorded the physical activity of all participants while they were immersed within the virtual environments and each session was logged in a time diary. So far QoE measurements have relied on subjective and objective evaluations. In this paper, we discuss the behavioral analysis of the effects of immersion and interaction on the simple active behaviors (movements + gestures) of the users. We apply quantitative behavioral observation to cross-examine user behavior against their self-reported responses to a "presence" questionnaire. We conclude that there is significant potential for applying cross-disciplinary behavior analysis tools to overall Quality of Experience within virtual environments.**

Keywords—immersive virtual environments, affordances, behavioral observation, video-based analysis.

I. INTRODUCTION

Virtual Reality (VR) is a powerful communication medium where users can freely move inside immersive virtual environments (IVEs) and enjoy its invoked agency, also referred to as a *sense of presence* [1]. From a Quality of Experience point-of-view this presents a challenge because immersive media is not just limited to passive 'viewing' experiences but have potential for active involvement on the part of the users. Advancements in commercially available headsets and tracking systems have profoundly contributed to human-computer interaction (HCI) research offering user-friendly locomotion and navigation techniques within IVEs.

Our lived experience in real world is derived from our action and movement in space over a temporal cycle [2]. Understandably, interaction and locomotion are also a prime consideration in IVEs. In fact, the production of a *place illusion,* or a *spatial presence* [1, 3] emerges when users IVEs respond to the visual and sensorimotor contingencies of the system. Thereby constructing mental models of the mediated environment in their minds where they can explore, move actively, interact, perform tasks, meet goals, achieve desires and experience various emotional states. To that end, immersive media make it possible for users to act out, think, and feel or express the range of human behavior, i.e. action, cognition, and emotion.

There is considerable research on usability and technical performance aspects of interfaces and techniques used for movement and locomotion in VR. Be it an empirical comparison of different VR locomotion techniques [4] or evaluating methods to promote intuitive free walking [5]. Insofar as covert processes are concerned, how users come to perceive locomotion in IVEs is also of interest to researchers [6]. Other studies have applied real world constraints within immersive walkthroughs to enhance user orientation and navigation skills [7]. Similarly, the use of subjective and physiological assessments to determine mind and body interactions of subjects performing inside immersive media has been especially attractive for QoE research [8, 9]. Works have often concentrated on evaluating user conduct within immersive media concerning cognitive loads, task performance efficiency, emotional valence, and social behaviors, to name a few. Whereas one notices a lack of comparative studies — inside and outside virtual environments — to determine the overall "naturalness" of a user's behavior. To questions whether a system/interface is aiding or impeding a user's natural and intuitive behavior.

Given this premise and inspired by the use of VR within behavioral studies [10], we investigated two distinct virtual architectural environments: a "passive walkthrough" vs. an "interactive walkthrough". Both environments are identical in their spatial experience however, the latter introduces interactivity features as well. Both experiences use physical walking along with the point-and-click teleportation technique for movement. We conducted behavioral observation of subjects to study if the overt-motor response of users corresponds to, or remains indifferent, to the addition of perceived-actions (interactivity) within the "interactive walkthrough". The study employed video-based observation, time-use survey, and self-reported pre/post-experience questionnaires to analyze user behavior in the two environments. The objective was to assess the influence of the change in IVE context on the user's exhibited behavior, and the interactions between the executed actions and observed physical movements of the user. This paper describes the experiment, examines its results, and discusses future work plans involving various behavioral observation methods.

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II. Related Works

A. Immersive Virtual "Architectural" Environments

Immersive media extend to technologies that yield an omnidirectional, spatial experience. Either superimposing or occluding the real-space altogether. Real-time rendering makes it possible to experience virtual architectural environments with correct scale and depth precision. They are used as visualization solutions in the design industry, environment models for immersive games, and as training environments for virtual learning. Three visualization options for immersive virtual reality applications are 360° Walkthrough, VR Walkthrough, and VR Interactive Walkthrough [11]. The success of IVEs owes to their familiarity with our real-world navigation, mapping, and manipulation techniques. Users not only apply their real-world skills within virtual environments but can also improve their spatial literacy and navigations awareness from training within them [7].

B. Quality of Experience in IVEs

User-perceived Quality of Experience is wholly described as a user's emotional response, involvement, and degree of interest in a media and/or application, etc. [12]. It is typically classified into system, context and human Influence Factors (IFs). Unlike passive media, in the case of immersive, multimodal applications, QoE relates foremost the "human experience" of a virtual environment. This experiential perspective, also understood as a *sense of presence* emerges out of the continuous interplay of immersion, interaction and involvement [13]. Any single aspect, alone, is not sufficient for sustaining prolonged user interest within immersive virtual environments unless buttressed by the other two. For this reason, user-perceived quality measurements of immersive technologies coincide with the multidisciplinary interest in measuring the elusive phenomenon of *presence* [1, 3, 13, 14].

C. Measuring Human Behavior

Spatial Presence (a subtype of Presence) is a subjective feeling of "being there" inside a mediated space. The feeling is brought on when a person *immerses* into a medium. This can be a low-tech media such as a book. Or in our case, immersion into mediated environments with a "continuous stream of stimuli" facilitated by immersive technologies [15]. A user is said to be in a state of immersion when they react to the affordances or action possibilities of the mediated environment with some degree of behavioral response.

How users appropriate the tools/interface at hand, how they interact, and how they moderate their actions? These are all important behavioral questions that enable us to optimize and improve the overall QoE of immersive applications. Kahneman [16] proposed two system of thought: System 1 (fast, instinctive, emotional); and System 2 (slow, deliberate, logical). Subjective QoE measurements that usually rely on surveys and questionnaires are excellent for capturing self-reported System 2 reflective processes such as skills, mental or emotional states, etc. However, questionnaires only provide a momentary glimpse into a person's actions, thoughts and emotions. More recently however physiological measures have been popularized to record reflexive System 1 processes and accessing covert and subconscious behaviors.

One can argue that since user behavior in IVEs is similar to human in real environment, it makes a strong case to observe and study subject behavior in both circumstances in order to understand them comparatively. Behavioral observation can be a handy tool towards this end. Observation methodology can be an effective tool in QoE measurements for assessing overt-motor responses and movement patterns of users while they're exploring IVEs.

III. Methodology

The goal of this study was to observe and investigate if the addition of interactivity features within IVEs affected human behavior outside. Further, if behavior changes correspond with the experiential performance of the IVEs. To achieve this, an empirical, comparative study with mixed methodologies was conducted to assess two IVE types. A within-subject experiment was designed to test participants in an identical virtual architectural model manipulating only the affordances of its environment. Giving us two independent conditions:

- Passive Walkthrough (PW), a fully immersive environment with no interactive features;
- Interactive Walkthrough (IW), a fully immersive-interactive environment with some basic affordances implemented.

A visually identical virtual environment and exposing each user to both conditions was intended to reduce errors associated with individual differences, minimizing random noise. The addition of affordances, or stimuli, was also intentionally kept controlled (discussed in subsection *C*). The study gathered self-reported data from profile surveys and post-experience presence questionnaires. An active-time diary was kept and detailed video streams for each participant in the study were recorded. The video data was subsequently coded to generate a time-use survey that was analyzed against the experiential quality scores for each participant to verify if:

Immersive-interactive environments (IW) will result in higher overt behavioral activity in users compared to less activity in non-interactive immersive environments (PW).

The experiment was designed with a single categorical group with two conditions: PW and IW. Participant behavior was observed into a single behavioral category of "locomotion", and subdivided into two types:

1) Durational, State Events: Sit, Stride, Sit

2) Non-Durational Point Events: Point-and-Click, Turn, Bend, Extend, Shrink (fold in).

A. Materials

1) Survey Instrument: The experiment used the cross-media validated Independent Television Company Sense of Presence Inventory (ITC-SOPI) to measure the experiential quality of the IVEs for each participant [17]. Participants responded questions on a 1–5 Likert Scale, later compiled in a Mean Opinion Score. We will consider results specific to Spatial Presence (SP) and Negative Effects (NE). Background profiling was also carried out with the same instrument.

2) Time log: An run-time log was created by the application for each use. A combined run-time of just over 10-Hrs was recorded for all participants in both experiences.

3) Video Data: Participant activity was video recorded while allowing for experimental control. Over 10-Hrs of video data was collected. The choice of video-based observation allows subjects to express themselves unobtrusively, at ease and facilitates natural behavior. All behaviors of interest was annotated to perform analysis and turn qualitative data into quantitative data.

4) Behavioral Observation: Video data was post-processed for analysis and observation coding inside an open source event logging software BORIS (Behavioral Observation Research Interactive Software [18]. All behaviors were coded into an ethogram, which include variables, conditions and states which are useful in subsequent analysis. Entries in the ethogram were made as state or point events, as mentioned earlier. Information was coded per subject separately for each participant. Although time logs varied for each use, a uniform 3-minute observation time was exercised. Event coding provides quantitative data for statistical analysis, reliability assessments and visualization.

B. Participants

Thirty-four participants (N = 34, Male/Female:18/16, μ = 26.7 $\pm$6.7) took part in the study. They were recruited via mailing lists, posted flyers, and online forms. All participants tried both conditions (PW, IW) in a randomized order. Participants were compensated with a single movie coupon. The experiment was pre-approved, and all participants provided written informed consent. Most participants had prior experience with VR headsets.

C. Environment

The virtual architectural environment was designed in-house using Trimble Sketchup. The virtual environment in both conditions, PW and IW, represents a one-bedroom layout stretching 32 feet on either side. The open-plan kitchen extends into the living room, which flows out onto a balcony overlooking a stream. The balcony is also accessible via the bedroom. Users can access the separate bathroom and storage space located at the entrance foyer as well.

1) Immersive Features: The model was populated with high-poly assets such as fixtures and furniture objects purchased from the asset store. All hi-res images used within the environment were retrieved from an online open-access repository. The model was exported into Unreal Engine where realistic texturing, lighting, and spatial soundscape was applied to enhance the immersive audio experience. The final environment was optimized for the HTC Vive Pro.

2) Interaction Features: Both conditions support natural walking and the point-and-click teleportation technique for navigation. Collider components were applied to the model to avoid unrealistic perforation effects of virtual surfaces. In the IW condition, additional interactive features have been used. These include 2 light toggles at the average eye-level, 6 operable doors at the average waist height, 2 cabinets and 1 drawer below the average waist height, 2 more drawers close to floor level, and 1 cabinet above head height. Height levels were used to assess the naturalness of user behvioral repsonse.

D. Equipment & Premises

The experiment was conducted in our virtual reality laboratory used for subjective and physiological assessments. It is approximately 5m × 5.7m with a fixed play area of 3.2m × 4.3m. The VR experience was run on a desktop PC operating on a 64-bit Windows 10 Pro with an Intel Core i7 7700 3.6 GHz processor, 32 GB DDR4 SDRAM (2,800 MHz), and a single 3GB NVIDIA GeForce GTX 1060 graphics card. The environment was presented to the

Fig. 1. Run-time activity for participants in IW and PW.

Fig. 2. Still vs. Stride Events in condition PW.

participants on the HTC Vive Pro head-mounted-display (HMD). This is a wired headset. It has a total resolution of (1440 x 1600 per eye) at a 90 Hz refresh rate. The headset features a 110° field of view (FoV), supports 3D spatial audio, and 6DOF head and motion tracking. The experience was simultaneously displayed on an external TV screen (Samsung 65" Full-HD). The screen was used by the experimenter to examine the activity of the participants and look out for unwanted artifacts and/or graphics malfunctions, such as lag, glitch, etc. Sessions were recorded with a SONY XDCAM at 4K resolutions and 50 fps.

E. Procedure

Testing sessions were prescheduled and were limited to a single participant at a time. An allocated session ran for 60 mins. Participants were received at the lab door by the experimenter. They were then asked to fill out a 10-item background information survey about their use of multimedia systems on a desktop PC. Next, participants tried on the HMD and familiarized themselves with the controllers through a quick tutorial. After this, participants were provided introduction to the experiment procedure. They confirmed their willingness by signing an informed consent form. The experiment was divided into two parts, i.e. passive-walkthrough (PW) and interactive-walkthrough (IW). The order was randomized throughout the sample to avoid carryover effects. Subjects were allowed to spend as much time in each condition as they desired (< 3mins) or found suitable for the exploration of the environment. Each condition was immediately followed by a questionnaire for experiential evaluation. A 5 minutes recess was observed between both conditions. Video recordings ran the length of one condition, i.e. two recordings per session. At the end of both sessions, participants were thanked with a movie coupon for their time.

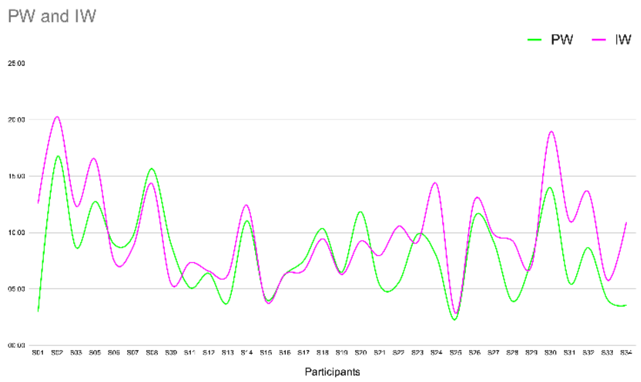

Fig. 3. Run-time activity for participants in IW and PW.

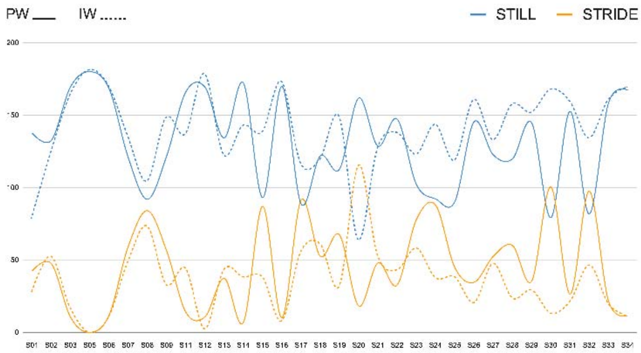

Fig. 4. Still vs. Stride Events in condition PW.

IV. Results

Thirty-four participants evaluated two immersive conditions. None of the participants had tried VR in a lab condition before. 10 participants reported no previous knowledge of VR, 15 participants had basic knowledge, while 9 reported intermediate knowledge of VR applications. A total of 68 experiences (N = 34 *X* 2 conditions/subject) were recorded. Two entire sessions (for subject S4 and S10) out of 34 were excluded from observation coding due to incomplete video data. Observations were limited to randomized time intervals of 3-mins per condition across all subjects. This was to bring uniformity since active-times for subjects varied significantly.

A. Time-Use Survey of Behavior

For condition PW, the run-time was 284min 25s (17065s) compared to 337min 38s (20258s) for condition IW. While the mean for IW ($\mu = 596$, $SD = 241$) was higher than that for PW ($\mu = 502$, $SD = 232$), an ANOVA result returned with no statistically significant differences in run-time for both conditions, IW and PW: $F(1, 62) = 2.64$, $p = 0.109$, partial $\eta^2 = 0.038$. Refer to Fig.1.

Next, a time-use assessment for the two dominant durational events (i.e. Still and Stride states) was carried out for both test conditions. Fig. 2 shows Still vs. Stride states in each condition. A proportion comparison for PW (Still/Stride:75/25) and IW (Still/Stride:79/21) are marginal. For the Stride state, the mean was higher in condition PW ($\mu = 44.92$, $SD = 29.8$) in relation to IW ($\mu = 36.2$, $SD = 23.03$). However, we found no significant differences between the two conditions: $F(1, 62) = 1.713$, $p = 0.195$, partial $\eta^2 = 0.027$. In the case of Still state, the mean was barely higher in IW ($\mu = 139.48$, $SD = 26.83$) compared to PW ($\mu = 133.6$, $SD = 32.8$). This also did not show a significant difference between PW and IW for the said state: $F(1, 62) = 0.621$, $p = 0.434$, partial $\eta^2 = 0.010$.

Further assessments were carried out for the frequent point events (i.e. Click, Turn and Bend). Turn and Bend events showed no statistically significant difference between the two conditions: $F(1, 62) = 2.209$, $p = 0.142$, partial $\eta^2 = 0.034$, and $F(1, 62) = 2.009$, $p = 0.161$, partial $\eta^2 = 0.031$. However, a significant difference was noted for Click events: $F(1, 62) = 4.771$, $p = 0.03$, partial $\eta^2 = 0.071$. Subjects recorded a higher frequency of Click events in IW ($\mu = 30.5$, $SD = 14.3$) in comparison to those recorded in PW ($\mu = 23.3$, $SD = 11.9$).

V. Discussions

We discuss the collective results by expanding our observational assessments to 5 individual subjects, specifically S8, S14, S23, S24, and S26. Subjects are selected based on their responses to the 18 questions on “Spatial Presence” (SP) and 4 questions on “Negative Effects” (NE) in the ITC-SOPI questionnaire. Both are rated on an absolute scale from 1–5. We will look at 4 subjects having the lowest and highest means for each condition, and 1 subject who appeared at the median for both conditions. In PW, subjects S14 and S24, whereas S26 and S23 in IW, were the highest and lowest respectively. S8 was at the median in both. Fig. 3 shows an event chart for the 5 subjects.

Subject	Condition	Durational (%)			Non-Durational (no.)				
		still	*stride*	*sit*	*click*	*turn*	*bend*	*extend*	*shrink*
S14	**PW**	97%	3%	0	21	14	0	0	0
	IW	79%	21%	0	55	23	0	0	1
S24	**PW**	51%	49%	0	17	19	0	0	0
	IW	79%	21%	0	20	8	0	0	0
S23	**PW**	57%	43%	0	12	19	0	0	0
	IW	70%	30%	0	18	21	0	0	0
S26	**PW**	81%	19%	0	29	11	1	1	0
	IW	88%	12%	0	22	24	5	1	1
S08	**PW**	51%	46%	0	24	4	2	0	0
	IW	59%	41%	0	20	14	5	6	1

Fig. 5. Event chart for Subjects in both conditions

Subject S14 undertook condition PW first. The active-time for the subject was 11mins 2s and registered the highest mean for SP ($\mu = 4.44$, $SD = 0.62$). Although the subject mostly remained stationary for the observed time (1min 30s - 4min 30s) and exercised very little body expression or movement. The subject recovered in second condition, IW, with a marked increase in lateral movement (i.e. strides) and a single bodily reaction was registered. The reported SP score by the subject for this condition was the third highest from the sample ($\mu = 4.39$, $SD = 0.69$). In contrast, subject S24 reported the lowest SP score ($\mu = 2.33$, $SD = 1.37$) in PW but the still-to-stride ratio was much even. Stationary events were regularly interrupted with movement. We find a better comparison by looking at the behavior of both subjects in IW. The overt durational behavior of S24 is similar in number to S14, but the former had more frequent transitions between the two states. The SP score for S24 ($\mu = 3.22$, $SD = 1.31$) in IW was below the sample median. The event plot in Fig. 4 compares both subjects.

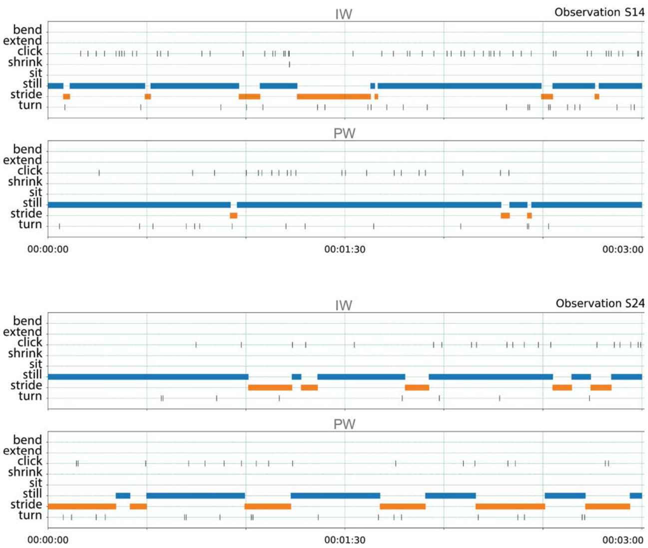

Fig. 6. Event logs for S14 and S24 under both conditions PW and IW.

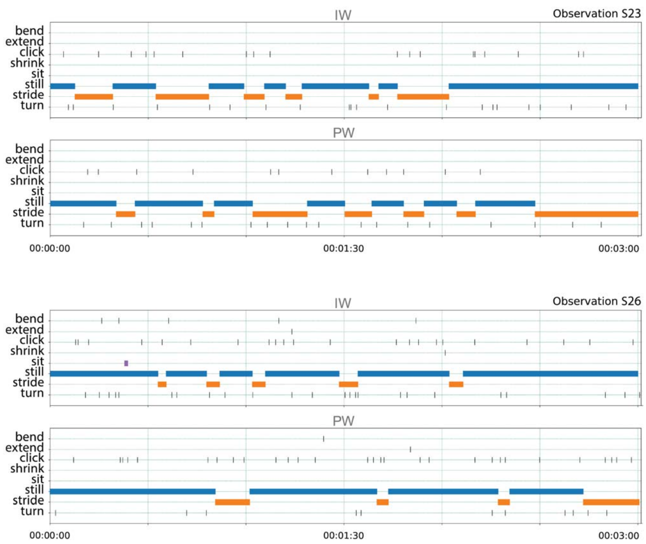

Fig. 7. Event logs for S23 and S26 under both conditions PW and IW.

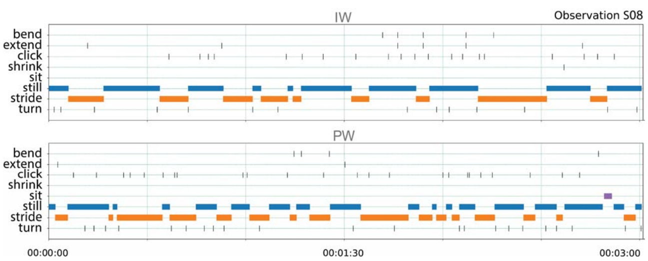

Fig. 8. Event logs for S8 under both conditions PW and IW

The highest SP within the IW condition was reported by S26 (μ = 4.67, *SD* = 1.03). The subject's activity on paper appears tilted towards Still events but these were regularly alternated by lateral movement and bodily gestures. The subject expressed all non-durational behaviors. Subject S26 carried over the behavior into their second undertaken condition, PW. The still-to-stride ratio is almost the same with intervals. Point events are also present. Though the loss of interactivity did not take effect on behavior it was reflected in a comparatively lower SP score (μ = 3.44, *SD* = 1.50). Subject S23 tried condition PW first and IW second. There is regular alternation between still and stride states in both conditions, but no other behavior events are noticed with the observed period. The interactivity features of IW did not produce any significant behavioral adjustment in the S23 neither did it inspire a positive SP score, which was reported as the lowest (μ = 2.89, *SD* = 1.28) by any subject within the sample. See Fig. 5 for event logs on S23 and S26.

Subject S08 provided the most diverse observation material (see Fig. 8). The subject scored at the median for both conditions PW (μ = 3.28, *SD* = 1.23) and IW (μ = 3.67, *SD* = 1.19). The subject behavioral response in both conditions is noted to be consistent. Still-to-stride state ratios are fairly even in length and frequent in occurrence. The subject was also most expressive with bodily gestures (see Fig. 6).

Of our 5 subjects, S14 demonstrated the most constrained behavior, which was contrasted by the bodily expressiveness of S08. A comparative analysis of frequencies of transitions

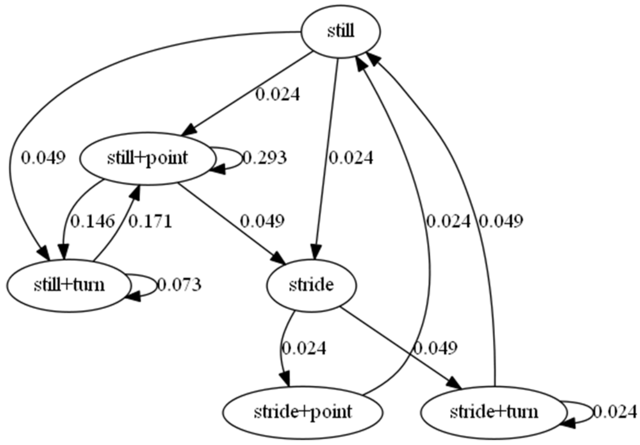

Fig. 9. Flow diagram for S14 in PW

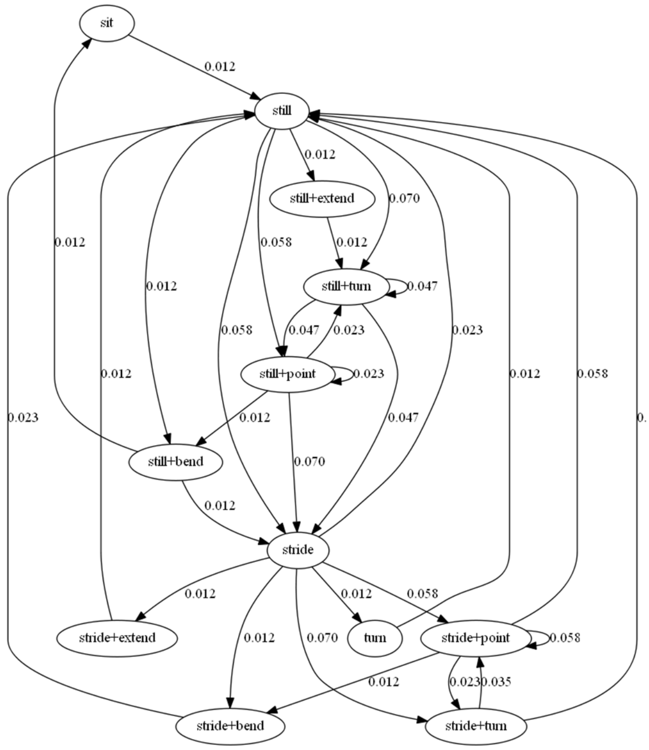

Fig. 10. Flow diagram for S8 in PW.

between S08 and S14 (Fig. 7 and Fig. 8) explains the complexity of their overt actions. In terms of “Negative Effects” (NE), we find S8 reporting a higher value consistently after both experiences, PW ($\mu = 3.6$, $SD = 1.14$) and IW ($\mu = 3.2$, $SD = 1.1$). It was hard to attribute this to the increased activity and transition frequency demonstrated by S8 compared to other subjects, since S23 also expressed frequent transitions and a balanced event share. However, S23 reported lower NE, PW ($\mu = 2.6$, $SD = 1.34$) and IW ($\mu = 2.0$, $SD = 0$). Interestingly, in the case of S14 who had the most stationary event demonstration also recorded a higher NE in PW ($\mu = 3.0$, $SD = 0.71$) compared to IW ($\mu = 1.6$, $SD = 091$) where the subject was more active.

VI. Conclusions

The aim of the experiment was to conduct a comparative assessment of user behavior within two distinct VR experiences and cross-analyze their behavior against the respective results from the ITC-SOPI measurements. We tried to determine if interaction features inside a virtual environment affect their overt-motor behavior on the outside. The results from observation analysis nullifies our hypothesis that subjects in IW condition will demonstrate a higher overt-motor response. Subjects remained mostly consistent in their behavior for both conditions. The longevity of state event, occurrence of frequent transitions and most point events remained fairly similar. However predictably, a significant difference was found in non-durational Click events that were higher for the condition with interactivity features. This also coincides with another observation made by the authors during testing that was the way in which subjects used the controllers, i.e. their appropriation of the tool-at-hand. Most subjects kept controllers close to their bodies. There were very few extensions (as evidenced in the event charts) even when the virtual environment demanded it. This could be a result of our long familiarity with techniques adopted from interactions with graphical user interfaces but requires further study.

From a QoE perspective, the study indicated that the overt-activity of users was responding more to Human IFs (of behavior patterns, propensity, motivation, etc.) even when virtual Contextual IFs (with the IVE) demanded an overt-motor response. This turns the argument towards the system IFs, in specific, interactivity and locomotion features. An obvious limitation is natural walking in VR especially inside a lab environment with limited space and room for movement. But an argument can be also be made that perhaps that perhaps locomotion techniques like click-and-point teleportation limit natural movement by preferring the age-old click-and-point technique. Users when allowed the choice fall on their digital literacy with immersive technologies rather than their spatial literacy that the technology also supposedly supports. This initial study provides a good premise for further investigations into comparing interactions within various different content, such as emotion-based, challenge-based, adventure-based, etc. This study, therefore, sees a potential for human behavior observation within QoE believing that we require a diverse array of cross-disciplinary tools to truly capture and understand the “human experience” of immersive media. Future works will address the limitations of this study, apply tailored virtual scenarios for instigated overt-behavioral responses in users, and expand into computer-based behavioral observation methods to complement the already established systems of subjective and psychophysiological evaluations.

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