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Utilizing Virtual Environments for the Evaluation of Lighting Controls

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Abstract

When designing a new user interaction (UI) technology or applying UI modalities to a product or system, the designer can select from many methods and tools to assist them with evaluating the UI's function and appeal with end users. Testing early in a design process is highly desirable since any issues found can be resolved more easily and often at less expense. However, for lighting solutions, these methods and tools are less suitable due to the qualities of light as a medium. Light is often detached from the UI itself and the light output is generally experienced throughout an environment which is often encompassing the users. For example, testing a new UI to control a yet to be installed media façade is not a simple system to mock up in advance, due to scale and cost. There is a need therefore, within the lighting industry, to have tools or methods with which design teams can test lighting UI, in conjunction with the light output, early in the design process. A potential solution is to use virtual environments. These would provide designers with a space in which they can show virtual light output that can be controlled using any developmental UI; this would enable them to evaluate lighting UI much earlier and potentially in more detail than is currently possible. In this paper we report on a user study that compares three different environments (physical, virtual CAVE and screen) in a bid to determine whether the virtual environments could provide reliable evaluations of UI for lighting versus a real setup. Our findings show that virtual environments indeed have the potential to elicit similar evaluative feedback from end users as a real environment when considering the functional utilitarian elements.

1. Introduction

The introduction of Light Emitting Diode (LED)-based lighting caused a revolution in the lighting domain as it enabled new to the world modes of illumination. The two key attributes of the LED over previous light sources are its small size and digital control. Consequently, one can easily increase the number and location of light sources along with the number of controllable outputs. This situation has created a need for new forms of lighting UI that can assist the end user in navigating between the light sources and altering the light output as desired (Aliakseyeu, Mason, Meerbeek, van Essen, Offermans & Lucero, 2011). Examples of new UIs include smartphone applications (Lucero, Lashina, & Terken, 2006), tangible-based UIs (Mason & Engelen, 2010), context and activity based lighting control (Offermans, van Essen & Eggen, 2011).

From these examples of new and upcoming lighting controls, made viable by the LED, it is clear that their variety and their potential breadth of control parameters provide the interaction designer with a complex task. Which would be the most optimal UI for a particular context? Which lighting parameters would need to be controlled? How would the designers be sure that the end users comprehended the solution? To answer this type of questions, user evaluation plays a crucial role, especially in the early phases of the design development process, when it is still possible to change direction at low cost. In many cases, the lighting effect is not localized to the light source but influences the feel and look of the complete environment. Subsequently, the sensation of presence (IJsselsteijn, & Riva, 2003), as well as the cognitive awareness of changes in the light's output, are also important aspects when evaluating lighting UI. Ideally, evaluating UI for lighting in the real environment is the most optimal situation since this requires no interpretation or imagination of the lighting effects or interaction. However, in many design projects this is often not possible. For example, the actual final environment may not yet exist in the case of lighting for a new building or location that is under redevelopment. Furthermore, these environments are likely to use expensive light features and infrastructure that must ideally work from the very first time, while having limited options for onsite testing, prior to project completion.

One solution that could assist the designer with testing user interaction ideas, early in a development cycle, is via the use of virtual reality and virtual environments that replicate the physical environment. This is where an environment, that may not yet exist physically, can be realized using 3D computer aided design (CAD) systems, in which a person can navigate and even interact with objects. The use of virtual environments has been quite successfully applied in spatial navigation (Conroy, 2001) and specifically, in wayfinding (Pramanik, 2006).

In the field of ubiquitous computing, where the context and environment play an important role, the use of virtual environments have been applied previously with promising results (Barton & Vijayaraghavan, 2002; Hühn, Khan, Lucero & Ketelaar, 2012; Leichtenstern, André & Rehm, 2010; Snowdon & Kray, 2009). The application domains varied from exploring the interface of a camera in a room (Barton & Vijayaraghavan, 2002), to evaluating location-based advertisement in a supermarket (Hühn et al., 2012), to researching whether users would apply different mobile interaction techniques in smart living rooms (Leichtenstern et al., 2009), to mobile navigation support for pedestrians in the countryside (Snowdon & Kray, 2009). The variety of applications for virtual environments implies that there is a potential of using this technology for evaluating lighting UI applications.

In this article we explore the applicability of virtual environments for testing user interaction with new lighting systems. In particular, we are interested in the following research question: does

the evaluation of lighting UI using virtual environments versus physical environments bear similar results?

In this paper we will first discuss related work in the areas of testing UI for lighting, virtual environments and virtual prototyping. Next, we present a user study with the three different environments for testing lighting UI. Finally, we discuss the results before formulating a number of guidelines for testing lighting UI concepts in a virtual environment.

2. Background

2.1 Testing UI for Lighting

Testing early in a design process is highly desirable since this can ensure problems and issues are identified early, when it is still possible to design alternative solutions. Many prototyping methods and tools exist to assist the designers with evaluating their ideas. For UI in particular, these tools range from the simple user interface sketches and wireframe modelling to more advanced tools, such as Unity or HTML5, for higher fidelity prototypes. Brown (2009) describes multiple ways designers may construct prototypes for assessing new products such as coffee machines or smart personal devices. However, designing a new UI for a lighting application presents some interesting challenges for which the aforementioned methods and testing examples are inadequate. Firstly, UI for lighting may indeed include a screen or be a web app, but the output from this UI would not only occur on the screen or a nearby product, but in the environment in general. Lighting is atmospheric and thus extends beyond the confines of a physical form, to influence the environment. How people perceive this, and the changes therein, can vary according to the individual (Flynn, Hendrick, Spencer, & Martyniuk, 1979; Sekulovski, Vogels, & Seuntiens, 2012). Thus, low fidelity sketches or static renderings may not provide the immersive feeling it would have in reality. Lighting can also be dynamic as it changes from one setting to the next and thus how people navigate a UI, and the corresponding light transitions need to be accounted for. For testing UI for lighting, users need to understand the consequences of their actions between the UI system and the light output they have set, or created. Since lighting is an environmental condition, the UI could easily extend beyond the screen or switches to include gestures, tangibles, or implicit interactions such as presence detection. Therefore, the physicality of the UI in the location and context is even more important in the case of lighting.

There is a number of lighting design tools available that can assist designers when developing lighting concepts; however, these concepts refer more to the light effects within an environment rather than the interaction with the light itself. For example, professional lighting designers use Dialux - a software package - to visualize a lighting scheme in an environment. The software can provide a realistic visualization of the space with the lights on, as well as providing data regarding the light intensity level, over the space that is useful when the design must conform to legislative requirements.

2.2 Virtual Prototyping and Lighting Tools

The lighting designer also has access to numerous other software packages that can simulate the light output from a luminaire in an environment, such as Maxwell, 3D Studio Max or Indigo. These can produce renderings that are of photorealistic quality and hence demonstrate, with a high degree of accuracy, how a luminaire and its light effect will be. Maxwell, for example, also has a

feature where the light sources within a rendering can be turned on or off, or have their color output changed. These can be used for evaluating the appeal of a concept.

Real time rendering software is also available in the form of game engines such as Unity. This is the platform that is used, for example, by Philips Lighting Retail Solutions, where the software will render a lighting scene according to the changes in the viewer's location, or according to different system configurations. For example, Philips has used such a solution to demonstrate the behavior of a lighting system, in a retail store, when the system includes multiple sensors that react according to the location of customers by altering the lighting to predefined conditions (Davitt, 2012). They would demonstrate this using a CAD model of the actual retail store. This package provides a simulation of a lighting system but does not enable direct interaction with a UI and the simulated lighting.

The choice of tool will depend on the purpose of simulation. For example, a photorealistic rendering can be used for the type of studies examining the visual perception of light, while more dynamic packages, such as Unity, can be employed for interactive evaluation including dynamic light effects. However, what confidence, with regard to real world representativeness, can be given to data collected using these tools for evaluating lighting UI?

In the next section we describe the user study where we evaluated three user interfaces: touch, gesture and tangible, for controlling lighting in three different environments: physical space, CAVE installation (Cave = cave automatic virtual environment: a room sized cube where a virtual reality environment is created using projectors that are directed to four walls around the user), and a single monitor system.

3. User study

The goal behind this study was to investigate if lighting UI could be evaluated using virtual environments and that data collected concurred with data collected from a real, physical environment. Robustness was designed into the study with the use of three different lighting interfaces (touch, gesture and tangible) to check if the findings were consistent for a variety of UI modalities.

Our initial null hypothesis would be that there are no perceived differences when it comes to users interacting with different techniques between the real environment and its virtual counterpart.

3.1 Setup

Three different setups were used in the experiment. The first was a real environment which was a typical looking living room situated within a lab. The second was an exact virtual replica of the aforementioned living room presented in a CAVE. The third is the same virtual living room presented on a monitor. Below we describe the setups in more detail. In all three setups a Wizard-of-Oz (WOz) protocol was used to link the lighting UI input with the lighting output in the environments. WOz protocols have been shown to be applicable to the evaluation of multimodal systems like the one we are applying in this study (Salber, & Coutaz, 1993).

3.1.1 Lab

The realistic living room was located within a laboratory setting of a home lab and it was equipped with a multitude of DMX controlled colored lighting fixtures; this was used as a physical

setup for this study. The light fixtures could all be controlled from an adjacent control room. For the experiment we made use of the Pharos Designer Software, with which we created the light scenes that were used in the experiment and were triggered during the experiment depending on the participants' actions.

Figure 1 shows a floor plan of the room with the location of light fixtures and Figure 2 shows two of the possible lighting settings. Participants controlled the UI from a location where they could observe the complete room without moving. To guide and support participants during the experiment, a set of markers were placed on the table in front of them (Figure 1 - markers are described in more detail in the "Tested interaction techniques" section.) Several cameras located in the ceiling were used by the wizard to observe the participants' actions and to then change the light settings accordingly.

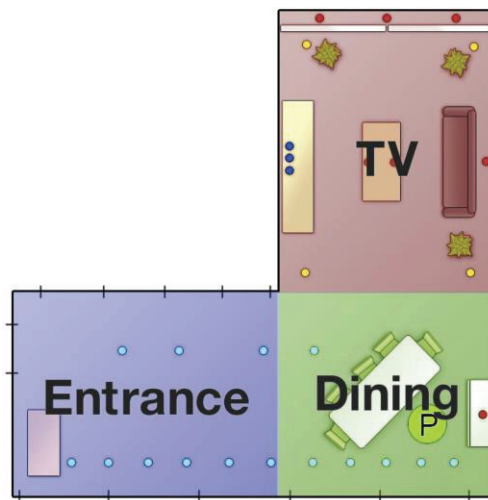


Figure 1. Homelab setup – floor plan. The letter P, seen at the dining area, indicates the location of the participant during the experiment.



Figure 2. Homelab setup lighting scenes

3.1.2 CAVE

Our CAVE consisted of four display screens of 3.5 meters wide by 2.6 meters high. These displays formed an enclosed room, and the images are back-projected on to them. The projections are calculated in such a way that, when a user stands in the room, the illusion of a continuous, 360-degree, view is created (Figure 3).

A table was placed inside the CAVE (Figure 4). The table was of identical size to the one in the physical living room lab. The identical setup set of markers that was used in the lab was also used in this setup to facilitate the use of the interfaces. The wizard, who was sitting next to the CAVE, was not visible to participants and with the help of two cameras was able to see the participants' actions in the CAVE.



Figure 3. The environment participants experienced in the CAVE setup



Figure 4. The table in the CAVE was setup to facilitate the use of the interfaces controlling the lighting in the virtual environment; the markers can be seen on the table.

3.1.3 Monitor

In the monitor setup we used the exact virtual living room as in the CAVE setup. The virtual environment was displayed on a widescreen monitor. The monitor was hung on a wall in a darkened room (Figure 5). To the sides of the monitor were stereo speakers and above it Microsoft Kinect. The Kinect did not actually serve any purpose other than to make the experience more believable when it came to the gesture interface. The participant faced this monitor from behind a table. The table was identical to one used in the CAVE. Regarding the details of the equipment we used, the table dimensions were (L,W,H): 180cm, 80cm, 74cm, the monitor was a LCD TV with diagonal resolution of 1280px by 720px. The participant's distance to edge of the table was approximately 25cm and the edge of the table distance to the monitor was approximately 110cm. Finally, the participant's distance to the monitor was approximately 215cm (figure 6).

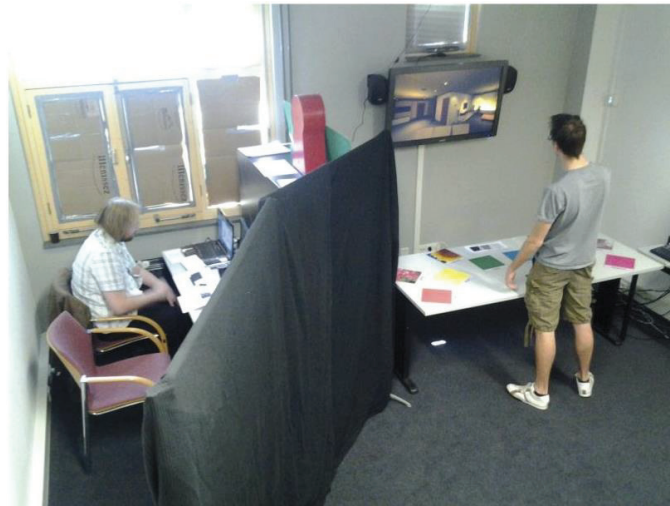


Figure 5. In the monitor setup the wizard was behind a curtain and not visible to participants.

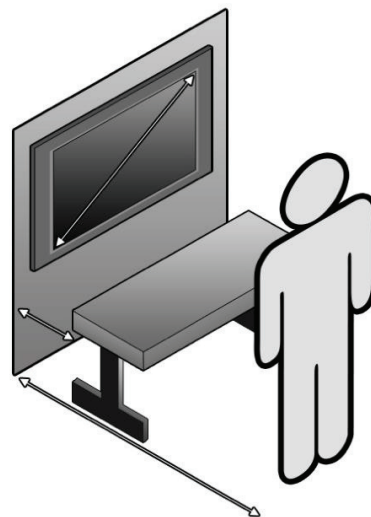


Figure 6. Monitor setup

3.1.4 Virtual Living Room

The virtual 3D environment was an exact replica of the lab’s living room (Figure 7). The objects of the virtual living room were modeled to scale and were identical to the objects of the real living room. The virtual environment was created based on measurement of real-life dimensions of the objects in the actual living room. These dimensions were translated into models and positioned using Maya. All objects were also given proper UV texture layouts. Textures were either found or hand crafted to replicate the real living room using a graphical editor. Because of the large number of combinations of different lighting setups that were possible, it was decided to display the room in real-time using the game engine Unity 3.4 Pro. This engine uses deferred lighting to generate real-time dynamic lighting solutions. Furthermore, Unity was also used to script functionality into the virtual living room. This functionality allowed the wizard to act quickly and, accordingly, based on what he perceived from the control room. Finally, the lights of the virtual reality environment behaved and operated identically to the lights in the real living room.



Figure 7. Screenshot of the virtual living room from Unity's interface

Modeling lighting conditions

As mentioned above the light conditions for different tasks were first created in the real environment using Pharos software. The light color values in Pharos were then recorded on a per light basis for each experimental condition and then used to set up the lights in the virtual environment. It is important to emphasize that the real-time virtual environment did not display entirely physically correct lighting scenes. The main difference between pre-rendered and real-time is the rendering time for a physically correct lit environment. For a virtual environment to be perceived as real-time it needs to be able to display at least up to 25 renders per second whereas a pre-rendered environment can take anywhere from an hour to several hours depending on the scene complexity and the computer's processing power.

The reason that we chose a real-time virtual environment over a pre-rendered environment was the sheer number of lighting possibilities that participants might have chosen and the number of high-resolution images that would be needed to accompany this.

Once the modeling and texturing stage of the experiment design were complete, the recorded Pharos lighting condition values were used for the light in the virtual environment. The result was that the virtual environment turned out to be darker than the lab. This is because of global illumination. When a light is cast on a 90-degree corner, where one wall is white and the other is green, one will be able to see the color from one wall on the other. Calculating global illumination is very processor intensive and therefore not common in real-time 3D environments. Additional area lights had to be placed to mimic global illumination and color values adjusted to approach the likeness of the lab.

3.2 Tasks

After the briefing participants about the procedure and signing the consent form, they were instructed on how to use the interaction techniques and were asked to complete a few training tasks. As soon as the training tasks were successfully completed, participants were given the experiment tasks. After completing each interaction condition participants evaluated the interaction. At the end of the experiment participants were also asked to evaluate the environment.

Each participant was asked to change the lights of the living room, virtual or real, using three different interfaces. The order in which the participant used the interface was predetermined and the order of use was counter balanced.

Each interface allowed participants to change the lighting of the living room based on global seasonal atmosphere, group based intensity and group based color. The seasonal option affected all the lights in the room with the purpose of changing the room’s atmosphere. There were four options to choose from: Spring, Summer, Autumn and Winter. The intensity option allowed participants to change the intensity of the TV area, the Dining table area or the entrance area (Figure 1) discretely from 10% to 50% and 100%. The color option allowed participants to change the color of the aforementioned groups to red, green, blue, cyan, magenta and yellow. Each choice took about two seconds to fully transition from a previous option to the new one.

Each interface provided audio feedback. The first sound played whenever a light altering command had been given to the system. A light altering command could be selecting a season or setting the intensity of the Entrance Area to 10%. The second sound played every time a task from the provided task list was performed correctly. These feedback sounds were played during both the training actual experimental phases.

3.3 Tested Interaction Techniques

3.3.1 Touch Interface

The touch interface (referred in the results as i1) was implemented using Unity 3.4, running on a Samsung Tablet Galaxy Tab 10.1 (Figure 8). Due to the WOz protocol, the application did not directly make changes to the light in either the real or virtual environments but rather sent messages to the wizard. The wizard then pressed an appropriate button corresponding to the participant’s choice. The tablet was placed on the dining table while the participant faced the table from the side with the least obstructed view.

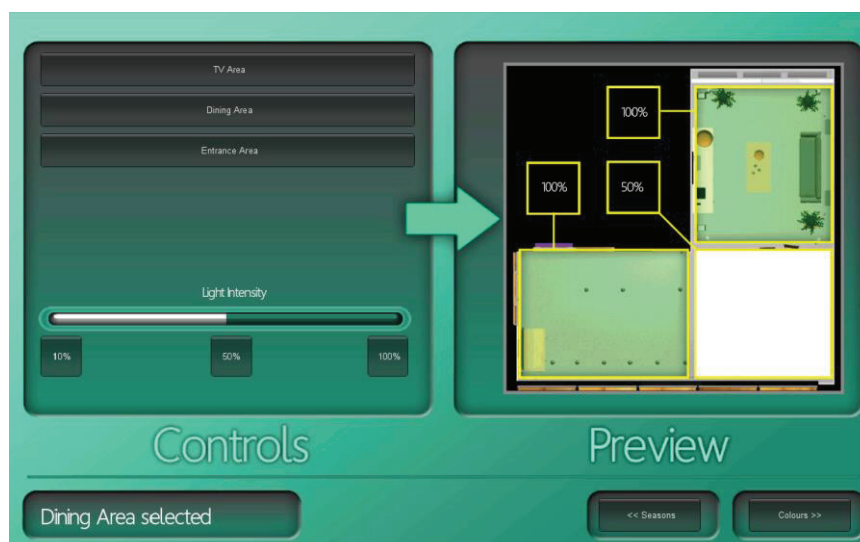


Figure 8. Screenshot of the tablet application. With this screen participants can change the light intensity in a certain area in the living room. In the right side participants can select one of the three areas (TV, dining, entrance) and in the left side set the light intensity to 10%, 50% or 100%.

3.3.2 Gesture Interface

In the gesture interface (referred in the results as i2), participants were asked to make arm and hand gestures to control the lights (Figure 9). Each participant stood in front of the table that displayed the gestures the system would recognize. Pointing towards a season would trigger that particular season. Pointing towards an area would select that area. The entrance area was selected by pointing at the door, selecting the dining table area was done by pointing up, and selecting the TV area was done by pointing towards the painting in the TV area. A confirmation sound accompanied each changing of season or selecting an area.

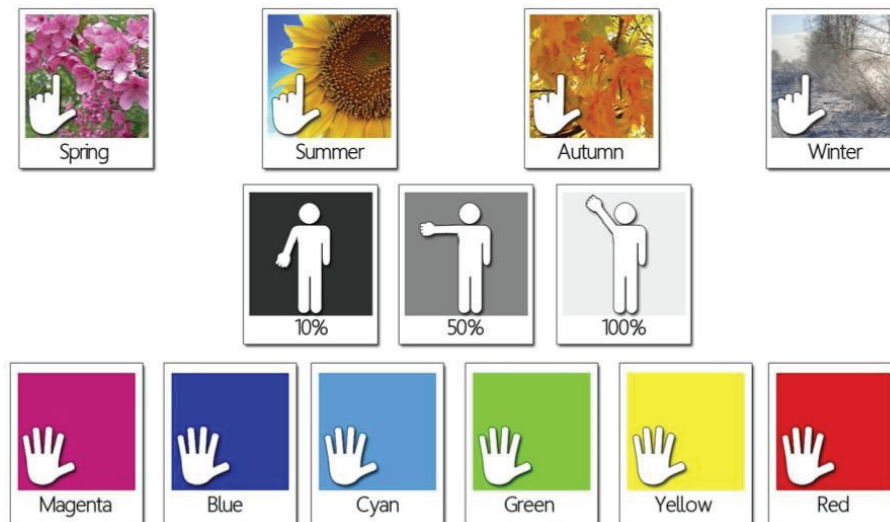


Figure 9. Instructions for gestures to control the light

After having selected an area, a participant could change the intensity and color of this area. Moving an arm in a lateral direction would, discretely, control the intensity by 10%, 50% or 100%. Positioning their open hand with their palm directed downwards over a color would activate that color for the selected area.

3.3.3 Tangible Interface

The tangible interface (referred in the results as i3) was placed on the table with the participant facing the table and TV area. The exact position where participants needed to stand was marked on the floor. The objects used for this interface were one black-red juggling ball and one white miniature lamp shaped object. Participants would position these two objects on the designated areas that indicated their choice (Figure 10). The ball was used to alter the seasons and to indicate an area. The lamp was used to change intensity and color. The season was always a predominant choice even if the lamp remained located on the color intensity section.

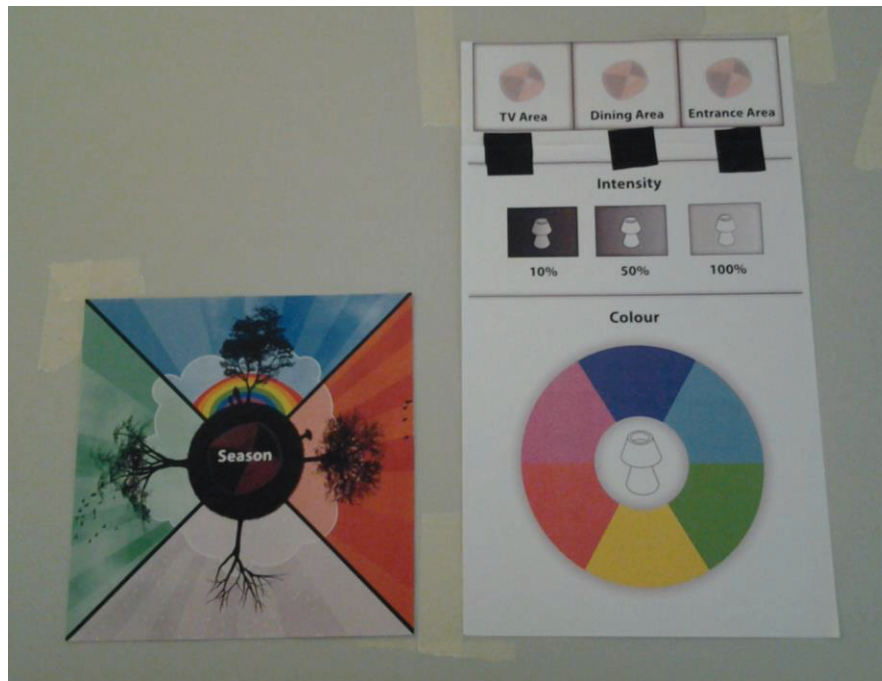


Figure 10. Moving a juggling ball and a white miniature lamp to a certain position on the table’s surface controlled the tangible interface. The possible choices were printed out and placed on the table’s surface.

These three different interaction modalities were selected for the following two reasons: firstly, there is a wide variety of interaction methods and thus focusing on a single modality would have limited the potential breadth and usefulness of any findings to a single UI form; secondly, the environmental setups tested in this research may have lent themselves more towards a particular type of UI and such findings would have been missed should have only one modality been included.

We designed the modalities to incorporate a varying degree of physical interaction since this may have had an effect on how the participants appraise the feeling of presence within the three environmental setups. The touch screen provided an almost private interaction. The tangible UI was a localized interaction, with the gesture UI requiring an open and highly physical action.

Participants

In total we recruited 74 participants. From those, 26 interacted with the three interaction techniques in the lab, 24 in the CAVE and 24 in the monitor setup. The order in which participants interacted with the techniques was counter balanced. We recruited 29 females and 45 males. The average age of participants was 33 years (SD=10.47). Occupations included: students (graduates or in the last year of studies), lecturers, managers, interns, researchers, project managers and HR professionals among others. Other collected demographics were: computer experience (91% intermediate or expert), TV viewing (0-8 hours 61%), TV size (15 to 28 inches 36% and more than 28 inches 30%), whether they have experienced 3D before (90% yes), knowledge of 3D (expert 9%), game time (occasionally and often but less than 50% of days 67%), education (bachelors-cumulative 51%), knowledge about TV/films (intermediate-cumulative 84%), whether they used VR before (yes 43%), knowledge about VR (expert 7%).

3.4 Measurements

We had two dependent variables: presence and users' attitude toward the interaction technique. For presence we used the ITC-SOPI questionnaire (Lessiter, Freeman Keogh, & Davidoff, 2001). Most studies measure presence through self-report Likert scales. Although there are several questionnaires that measure presence, the ITC-SOPI questionnaire seems to be widely used by related research. The ITC-SOPI is based upon 604 responses (Lessiter et al., 2001) across a variety of media formats and content. Moreover, this questionnaire can be used for cross-media purposes; that makes this questionnaire more applicable for our experiment, since we have three different setups. This questionnaire, apart from querying participant's background information, it includes the following four dimensions: *spatial presence*, *engagement*, *ecological validity* and *negative effects*.

For assessing users' attitude toward the interaction we chose to use HED/UT scale (Hassenzahl, Platz, Burmester & Lehner, 2000). The main reason for selecting this questionnaire was the prospect of assessing both the utilitarian and hedonic qualities of the UIs. Moreover, we expected that different environments might have a stronger impact on the assessment of hedonic quality.

4. Results

There are direct and indirect comparisons one can conduct for the different setups. A direct comparison would be between setups, whereas an indirect comparison would be within a certain setup. The analysis that follows was based on both direct and indirect comparisons.

4.1 Comparison Between Setups

4.1.1 Utilitarian and Hedonic Aspects

We used an unrelated one-way ANOVA to analyze the data. We found that there was no significant effect of the independent variable on both the dependent variables for any of the interaction techniques. More specifically, for the utilitarian aspect of touch, $F(2,70)=.495$, $p=.612$; of gesture, $F(2,70)=.012$, $p=.988$ and finally of tangible, $F(2,70)=.239$, $p=.788$. Furthermore, for the hedonic aspect of touch, $F(2,70)=.340$, $p=.713$; of gesture, $F(2,70)=1.837$, $p=.167$ and finally of tangible, $F(2,70)=.423$, $p=.657$.

4.1.2 Presence

In terms of presence, we found that there was a significant effect of the independent variable on two aspects of presence: spatial presence and ecological validity, whereas there was no effect for engagement and negative effects (Table 1). The mean values for the lab group ($M=3.62$) indicate greater spatial presence than for the CAVE group ($M=3.13$) and the monitor group ($M=2.79$). The mean values for the lab group ($M=3.92$) indicate greater ecological validity than for the CAVE ($M=3.54$) group and the monitor group ($M=3.33$).

Table 1. Results for the effect of setup on dimensions of presence

Spatial presence	F(2,70)=8.324, p=.001**
Engagement	F(2,70)=.273, p=.762
Ecological validity	F(2,70)=4.299, p=.017*
Negative effects	F(2,70)=.189, p=.829

4.2 Comparisons Within Setups

The indirect way of comparing the setups is to see how users feel about the interaction techniques within the different setups, in particular, to see if the evaluation of techniques is consistent across the three setups or if some techniques ranked significantly better in one setup and not in other. For all comparison below we have used a related-samples ANOVA.

4.2.1 Lab

Utilitarian Aspect

We found that there was a significant effect of the independent variable interaction technique on the dependent variable utilitarian, $F(2,46)=5.614, p=.007$.

A further related samples t-test shows (Table 2 – row 1) that the utilitarian aspect of touch ($M=2.71, SD=.68$) was perceived significantly better than that of gesture ($M=3.18, SD=.89$). A comparison between the means of the groups’ perception of touch and gesture was significant ($t(23)=-2.74, p=.012$). Moreover, the utilitarian aspect of touch ($M=2.71, SD=.68$) was perceived significantly better than that of tangible ($M=3.23, SD=.67$). A comparison between the means of the groups’ perception of touch and tangible was significant ($t(23)=-2.972, p=.007$). Finally, the utilitarian aspect of gesture ($M=3.18, SD=.89$) was perceived slightly better than that of tangible ($M=3.23, SD=.67$). A comparison between the means of the groups’ perception of gesture and tangible was not significant ($t(23)=-.349, p=.73$).

Table 2. Overview of results when comparing within each setups the utilitarian aspects of the three interaction techniques.

	<i>Touch compared to Gesture</i>	<i>Touch compared to Tangible</i>	<i>Gesture compared to Tangible</i>
Lab	Sig*	Sig**	Not sig
CAVE	Sig**	Sig**	Not sig
Monitor	Sig*	Sig**	Not sig

Table 3. Overview of results when comparing within each setups the hedonic aspects of the three interaction techniques

	<i>Touch compared to Gesture</i>	<i>Touch compared to Tangible</i>	<i>Gesture compared to Tangible</i>
Lab	Sig*	Not sig	Sig*
CAVE	Not sig	Not sig	Not sig
Monitor	Not sig	Not sig	Not sig

Hedonic Aspect

We found that there was a significant effect of the independent variable interaction technique on the dependent variable hedonic, $F(2,46)=3.439$, $p=.041$.

A further related samples t-test shows (Table 3 – row 1) that the hedonic aspect of touch ($M=4.74$, $SD=.32$) was perceived significantly better than that of gesture ($M=4.96$, $SD=.45$). A comparison between the means of the groups’ perception of touch and gesture was significant ($t(23)=-2.160$, $p=.041$). Moreover, the hedonic aspect of touch ($M=4.74$, $SD=.32$) was perceived slightly worse than that of tangible ($M=4.73$, $SD=.39$). A comparison between the means of the groups’ perception of touch and tangible was not significant ($t(23)=.069$, $p=.945$). Finally, the hedonic aspect of gesture ($M=4.96$, $SD=.45$) was perceived significantly worse than that of tangible ($M=4.73$, $SD=.39$). A comparison between the means of the groups’ perception of gesture and tangible was significant ($t(23)=2.46$, $p=.022$).

4.2.2 CAVE

Utilitarian Aspect

We found that there was a significant effect of the independent variable interaction technique on the dependent variable utilitarian, $F(2,46)=5.614$, $p=.007$.

A further related samples t-test shows (Table 2 – row 2) that the utilitarian aspect of touch ($M=2.71$, $SD=.73$) was perceived significantly better than that of gesture ($M=3.15$, $SD=.79$). A comparison between the means of the groups’ perception of touch and gesture was significant ($t(22)=-4.11$, $p=.0004$). Moreover, the utilitarian perception of touch ($M=2.71$, $SD=.73$) was perceived significantly better than that of tangible ($M=3.44$, $SD=.79$). A comparison between the means of the groups’ perception of touch and tangible was significant ($t(22)=-5.103$, $p=.000041$). Finally, the utilitarian perception of gesture ($M=3.15$, $SD=.79$) was perceived slightly better than that of tangible ($M=3.44$, $SD=.79$). A comparison between the means of the groups’ perception of gesture and tangible was not significant ($t(22)=-1.801$, $p=.085$).

Hedonic aspect

We found that there was no significant effect of the independent variable interaction technique on the dependent variable hedonic, $F(2,42)=1.619$, $p=.210$ (Table 3 – row 2).

4.2.3 Monitor

Utilitarian Aspect

We found that there was a significant effect of the independent variable interaction technique on the dependent variable utilitarian, $F(2,44)=5.856$, $p=.006$.

A further related samples t-test shows (Table 2 – row 3) that the utilitarian aspect of touch ($M=2.54$, $SD=.79$) was perceived significantly better than that of gesture ($M=3.11$, $SD=1.05$). A comparison between the means of the groups' perception of touch and gesture was significant ($t(22)=-2.125$, $p=.035$). Moreover, the utilitarian aspect of touch ($M=2.54$, $SD=.79$) was perceived significantly better than that of tangible ($M=3.32$, $SD=.95$). A comparison between the means of the groups' perception of touch and tangible was significant ($t(22)=-4.235$, $p=.00034$). Finally, the utilitarian aspect of gesture ($M=3.11$, $SD=1.03$) was perceived slightly better than that of tangible ($M=3.30$, $SD=.94$). A comparison between the means of the groups' perception of gesture and tangible was not significant ($t(23)=-.735$, $p=.47$).

Hedonic aspect

We found that there was no significant effect of the independent variable interaction technique on the dependent variable hedonic, $F(2,44)=.887$, $p=.419$ (Table 3 – row 3).

4.2.4 Summary of UI Preferences

It is evident that the utility of Touch is preferable to Gesture and Tangible in all three setups. Therefore, Touch is the preferred interaction when it comes to utilitarian aspects. In case of hedonic aspect, it is evident that the setup has an effect on the evaluation of the interaction techniques. In the Lab setup we find that Touch is preferred to Gesture and Gesture is preferred to Tangible. Yet we do not observe such a difference in the other setups.

4.2.5 Analysis of Equivalence

From the aforementioned results we find the lab having a relative advantage when it comes to some aspects of presence; namely hedonic aspects of interaction techniques. However, our main question of whether virtual environments could be used for evaluating interaction design techniques is still unanswered when it comes to utilitarian aspects of interaction techniques. The fact that the data do not exhibit significant differences between the setups, when it came to utilitarian aspects of the three interaction techniques, does not necessarily mean equivalence of those setups. Thus, it is important for our purposes to further analyze the data, to find whether practical equivalence is actually achieved by virtual environments.

For that purpose, the t-test would not be of any help. An alternative test, the two one-sided t-test (TOST) “*begins with a null hypothesis that the two mean values are not equivalent, then attempts to demonstrate that they are equivalent within a practical, preset limit*” (Limentani, Ringo, Ye, Bergquist & McSorley 2005). TOST was originally designed for bioequivalence testing of pharmaceutical products but has recently expanded into process engineering, psychology, medicine, chemistry and environmental science (Limentani et al., 2005). The challenge for the researcher applying this test is to define an acceptance criterion based on previous knowledge and the intended application. This acceptance criterion is symbolized by the Greek letter theta (θ). The researcher then needs to calculate the $100(1-2\alpha)\%$ confidence interval for the difference between the two sample mean values. If that confidence interval is entirely contained within the interval $(-\theta, \theta)$, then one can conclude that the groups are similar.

The challenge as aforementioned is in defining the acceptance criterion θ . Since there is no prior research that would inform us what an acceptance difference would be - to decide when two interaction techniques would be consider similar - we need to define it based on logical arguments. Since the utilitarian scale is a seven-point scale and, if we assume that it is an interval scale, we would argue that any differences below 10% could be considered as practically similar. Thus, 10% in

a seven-point scale would mean $\theta=.7$. Furthermore, if we set $\alpha=.05$ the $100(1-2\alpha)\%$ confidence interval would equal 10%.

In equivalence testing, hypotheses are formulated in a way that the statistical test is proof of similarity (Barker, Luman, McCauley & Chu, 2002). Thus, in comparing the *Lab* with the *CAVE* we would formulate the following hypotheses:

H0: the perception in the *Lab* of the utilitarian aspects of the interaction techniques is dissimilar to the perception in the *CAVE*.

H1: the perception in the *Lab* of the utilitarian aspects of the interaction techniques is similar to the perception in the *CAVE*.

The 90% confidence intervals for the utilitarian aspect of the three interaction techniques were: touch (-.346, .349), gesture (-.390, .439), tangible (-.572, .152). Since all three intervals are entirely contained within the interval $(-.7, .7)$ we can reject the null hypothesis and accept the alternative. Therefore, we conclude that for the purpose of evaluating utilitarian aspects of interaction, the *CAVE* is equivalent to the *Lab*.

Furthermore, in comparing the *Lab* with the *Monitor* we would formulate the following hypotheses:

H0: the perception in the *Lab* of the utilitarian aspects of the interaction techniques is dissimilar to the perception in the *Monitor*.

H1: the perception in the *Lab* of the utilitarian aspects of the interaction techniques is similar to the perception in the *Monitor*.

The 90% confidence intervals for the utilitarian aspect of the three interaction techniques were: touch(-.194, .530), gesture(-.414, .543), tangible(-.495, .314). Since all three intervals are entirely contained within the interval $(-.7, .7)$, we can reject the null hypothesis and accept the alternative. Therefore, we conclude that for the purpose of evaluating utilitarian aspects of interaction the *CAVE* is equivalent to the *Monitor*.

5. Discussion

On the one hand, the virtual installation we used seems incapable of replicating experiential aspects such as presence and hedonic aspects of interaction techniques. On the other hand, when it comes to utilitarian aspects of interaction techniques, both the *CAVE* and the monitor setup yielded equivalent results. That would mean that a monitor installation would be preferable when it comes to evaluating utilitarian aspects of interaction techniques for light. A monitor setup is less costly, requires less space and less complex computer configuration to execute.

When it comes to the users' preference of an interaction technique, results are much clearer. In all setups and for both utilitarian and hedonic aspects the touch (tablet) interface was superior to gesture and tangible interfaces. One can argue that participants are more familiar with touch interfaces and less with gesture and tangible ones. Therefore, they might prefer something that is more known to them when compared to something less known. There is certainly more research needed to uncover why this is a prevalent preference. Furthermore, since the touch interface was an actual Android app it might have looked more professional in appearance when compared with the tangible and gesture UIs, and thus may have influenced the participants' preference. Future research

needs to shed more light into this finding by investigating more carefully participants' experience and preference of different interfaces.

6. Conclusion and Future Work

We conducted research to compare setups of physical and virtual environments (in a CAVE and a single monitor) for evaluating UI (touch, gesture, tangible) for lighting. The findings were not conclusively in favor of one particular setup being better than another. The physical environment, as expected, enabled the participants to have a slightly greater feeling of presence than the other virtual setups. The UIs experienced in this environment also elicited higher hedonic values suggesting that the virtual environments failed to portray the full experience of interacting with the light.

Nevertheless, when the utilitarian factor was taken into account, very little seemed to separate the results from the three setups. One possible conclusion we can draw from this is that the functional aspects of lighting UI can reasonably be evaluated using virtual environments. We conclude that researchers can use a simple monitor setup to determine end users' preference of a UI's utility for lighting instead of a CAVE environment. This would indeed allow for fast and early testing of the most important UI elements. The hedonic values however, may require evaluation at a later stage in a development process when the UI can be applied in a physical environment, be that a lab or the actual intended location.

The fact that there was an overall preference for the tablet (touch) UI does not affect the above assessment of when to use the various setups, but it may be more reflective of the time in which we live. Tablet UIs are highly popular and many people aspire to own or use a tablet PC. This UI was also more professional in appearance when compared with the tangible and gesture UIs, and thus may have influenced the participants' preference.

This research was a first step into exploring how to provide reliable means of evaluating UI for lighting, especially during the early phases of a design and development process. Future work in this area could include the comparison of other VR modalities with physical environments, since other modalities and setups are available. The research design could also be incorporated into a real project as a case study, perhaps with a comparison between VR, experience lab setup and the final installation.

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