Manipulating Puppets in VR

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ABSTRACT

Archiving Performative Objects aimed at applying and conserving puppetry as creative practice in VR. It included 3D scanning and interaction design to capture puppets and their varying control schemes from the archives of the *Center for Puppetry Arts*. This paper reports on their design and implementation in a VR puppetry set up. Its focuses on the evaluation study (n=18) comparing the interaction of non-experts vs expert puppeteers. The data initially show little differences but a more detailed discussion indicates differing qualitative assessments of puppetry that support its value for VR. Results suggests successful creative activation especially among experts.

Keywords: Puppetry; Virtual Reality; interaction design.

Index Terms: Human-centered computing – Human computer Interaction (HCI) – Interaction paradigms - - Virtual reality

1 INTRODUCTION

Can puppetry inform effective interaction design to support creative engagement in Virtual Reality (VR)? The significance of puppetry as a creative practice itself is unquestionable. Forms of puppetry can be found on every continent, the format transcends cultural, racial, or educational boundaries. As a cultural practice it has grown over millennia into countless manifestations that range from tribal rituals to transmedia practices. Puppetry has been used both to question and challenge social conditions, as well as the means to represent their status quo [1]. Puppets offer an encounter with material forces that provides the "concrete means of playing with new embodiments of humanity. To understand our engagement with puppetry is to chart and reveal new expressions of ourselves." [2] Building on this cultural anchoring, the *Archiving Performative Objects* project focused on puppets as performative objects. It successfully implemented sample puppet designs and adapted physical puppet manipulations into VR. The goal of this paper is to report on this puppet mediation as an interaction design approach informed by traditional cultural practice.

The paper is structured into three main sections: first, it will briefly outline the role of puppetry in HCI; second, it will introduce the design and implementation of *Archiving Performative Objects*; third, it will present the project's final user study and discuss the results. The focus will be less on the interface technologies and more on this third section. We specifically ask whether experts of puppetry will perceive interaction with a puppetry-based VR interface differently than non-experts. Underlying this question is the search for creative, culturally situated interfaces for VR. Can we use puppetry as an interaction metaphor for emerging VR interaction design and do the manipulation mechanics of puppets enable a creative engagement with virtual characters? In this case, we targeted a comparison between expert puppeteers, who professionally work with traditional puppets as creative objects, and amateurs, who might recognize puppets as expressive but lack the skills to fully explore their expressive range. Can we trace any distinctive creative engagement between these different populations?

The comparative study helped to identify possible differences between users with prior knowledge of the interface nature and those who were untrained in the cultural richness of the underlying interface metaphor. The paper closes with an outlook on future work and possible developments based on these results.

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2 PUPPETS AND HCI

Puppetry has been used as a point of reference in Human Computer Interaction (HCI) since the early 90s, when Walser introduced a cybernetic feedback loop in which "the puppet gives the patron a virtual body, and the patron gives the puppet a personality" [3]. This already connected puppetry to a form of "embodiment" [2] and reinforced puppetry as an early performance-based interaction design approach [4]. It consecutively drove the use of puppetry in numerous projects that focus e.g. on education [5], animation [6], tangible interfaces [7], tangible VR [8], or robotics [9], among other domains. Initial frameworks were suggested (e.g. for tangibles [10] or for video games [11]) but the development of the field is dominated by individual projects. As each project provides its own unique solutions, interaction challenges are tackled through the unique assimilation of specific puppetry mechanics. In these cases, puppetry approaches are references, deployed as means to an end in the design challenge. The focus is not on an investigation of puppetry as a cultural expressive form *per se*.

A second connection between HCI and puppetry emerged in the area of virtual heritage. Here, digital means assist in puppet conservation and education. This is particularly true for shadow puppetry, which has seen a number of virtual realizations and own initial frameworks [12]. These projects foreground puppetry practice within a larger cultural tradition, one they see endangered by modern media developments such as video games [13, 14]. Projects in this trajectory often develop computational methods that utilize and remediate shadow puppetry practice. For example, they analyze user movement for procedural animation generation [15]. Or they scan and translate human bodies onto shadow puppets [13]. To highlight one project: *ShadowStory* uses custom-built sensors as input devices to control user-created shadow puppets. The project was conceived as an educational tool and as a digital intervention to widen access to traditional Chinese shadow puppetry. The researchers were motivated by their observation that only 1 out of the 36 participating Chinese school children had ever encountered shadow puppetry as a live art form. To counter this, Lu et al. implemented a project, where students can design own virtual shadow puppets and control them via customized sensors to develop and share stories [14]. But *ShadowStory* remains limited to custom-built hardware and specialized (and largely inaccessible) software. Project like *ShadowStory* show that puppet-based interaction design provides the means to support, educate, and conserve. But while the results are promising, they remain difficult to transfer to other projects.

The *Archiving Performative Objects* project sits in-between these two approaches and combines interaction design challenges

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with a virtual heritage approach. It is informed both, by HCI as well as puppetry scholarship and practice. The original motivation for the project was the challenge to provide a prototype allowing access to the puppets stored in the archive of the *Center for Puppetry Arts* through digital media. The archive contains over 3000 objects that include puppets from a wide cultural range. Only a fraction of the collection is displayed in the center's museum and there is no direct access to any of the objects for scholars, artists, or visitors to the museum.

Archiving Performative Objects argued that any archival function had to include interactive options as the very nature of puppets requires manipulation. Puppets' expressive range only comes into being through play. Thus, the project experimented with an interaction design to present the selected puppets not only as visual objects to look at, but as active objects to perform with.

3 PROJECT DESIGN

In collaboration with the *Center for Puppetry Arts*, the researchers of the *Archiving Performative Objects* project selected a range of different puppets from the archive. They performed 3D scans of these functionally very different puppets, rigged and optimized the geometry for real-time 3D, integrated them into a web 3D viewer, and implemented them into a VR environment. Through both realizations, the project experimented with access to virtual puppet versions as interactive objects. Puppetry is not approached as a historic reference for archival use but as material *practice*. Consequently, the interaction design emerged from this practice as well as the objects at hand. Recreating the objects in 3D addressed only the first challenge of mediation. The second was to map a puppeteer's controls onto those digital models.

The combined results are mediated puppets, "media figures," for which puppetry scholar Tillis argues, that their presence is "created by the medium. They are not media reproductions, that is, but original productions made possible through media." [16]. As we will argue later, such media figures lack the tangibility of physical puppets but they create their own performance conditions. The following sections will outline the project before focusing on the evaluation of the interface.

3.1 Design and Implementation

The project unfolded over multiple stages beginning with the selection of a range of puppet objects stored in the archives of the *Center for Puppetry Arts*. To cover key manipulation methods, over a dozen puppets were selected and scanned for the project overall. Physical puppets are highly individual expressive objects. They usually feature unique controls and we cannot claim to cover all possible approaches. But covering key manipulation techniques guaranteed a basic variety.

Scanning was conducted with a FaroArm offering a scanning precision up to ~ 0.001 in. This led to high precision 3D scan data that could not directly be translated into the real-time 3D engine. The digitized sample puppets had to be optimized, modeled, and rigged in a 3D package (Autodesk's Maya and 3D Studio) to suit the target 3D engine (Unity). Once imported into Unity, the final prototype used an HTC Vive VR set up connected to a high-end consumer PC (Intel i7-6700/ 3.4Ghz and a Radeon RX 480 graphics card) for a local consumer-level VR set up.

A second instantiation of the 3D models was made available online as re-imagination of *Center for Puppetry Arts*' online archive. It included interactive 3D puppets offering limited controls through desktop interaction in a Web 3D interface. This paper will not focus on the technicalities and design choices in regard to this digital archiving work but will focus on the challenges and results of the VR portion instead.

Figure 1: Kasper puppet from original photos (upper left) to 3D scan data (upper right), to optimized 3D model (lower left) to appearance of the puppet on the VR stage (lower right).

3.2 Principle Interaction Design

The project selection covered key puppetry concepts: object, rod, shadow, hand puppets, and various marionettes. Each of these puppet types features specific own control mechanisms. In addition, actual controls of individual puppets are unique to the particular puppet object. For example, different marionette puppets used varying numbers of strings and different controllers for their manipulation, shadow puppets were manipulated with two or three sticks, rod puppets ranged from single rod controls to multiple control ones. There is no single puppetry control scheme across different categories, nor is there a given one within any one category [17] or a single history of such controls [1]. Thus, each control mechanism was based on the specific physical puppet's conditions. This includes length of rod or string controls, simulated joints, or the size and shape of the manipulators.

All VR interactions had to map onto the Vive's VR controllers as we adapted them from the existing puppets and their handling. In this way, the controls were based on traditional manipulation approaches as well as on the limitations of current VR interfaces. Their differences remained obvious, which is why we approached them less as technical recreations and more as forms of remediation (following [18]).

The principle mapping concept drew from work by puppet scholar Stephen Kaplin, who proposes to map puppet controls along two axes: *distance* and controller *ratio*. Kaplin uses these dimensions to map out a “puppet tree” that includes puppets from “close” distances and a “one puppeteer controlling one puppet” ratio, to multi-puppeteer-controlled massive performance objects that can be in great distances from the actual puppeteer(s) [19]. One of the benefits of Kaplin’s puppet tree is that it extends into the digital. He includes, for example, video game characters as well as the large-scale puppets of the *Bread and Puppet Theater* and robots. *Archiving Performative Objects* targeted a single-user implementation and, thus, did not realize the “ratio” axis, which depends on multiple performers. The “distance” axis, however, was key to the overall design. Kaplin defines distance as “the level of separation and contact between the performer and the object being manipulated” [19]. He differentiates it into individual puppetry techniques. This level of distance inspired our main abstraction model to map puppet controls from the body and positioning of the puppeteer to the fingers and respectively the extremities of the individual puppets.

Ultimately, this broad scaling model helped to structure the different design approaches for the puppets and kept the interaction design coherent between puppets types and within our given limitations of a commercially available VR system.

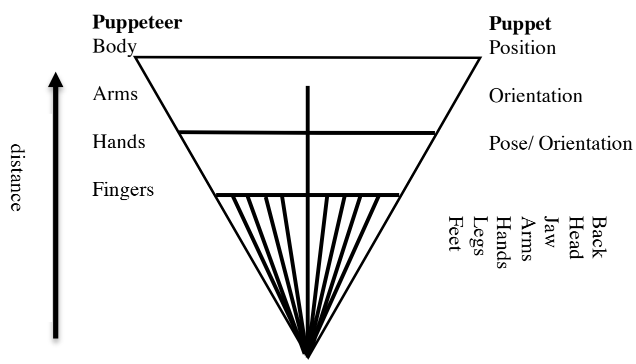

Figure 2: Basic Interaction design scaling toward distance.

Whenever specific puppets would require a fundamental adjustment that would break this coherence, we adjusted them or excluded those models from our final testing. For example, we mapped hand puppet controls onto a scanned 3D model following the same basic approach. In this case, the full puppet was controlled by the orientation of the puppeteer’s right hand. The puppet’s head was controlled by the right thumb of the puppeteer using the Vive’s touch pad. These hand puppets were the only puppets that utilized the touch pad features on the Vive controllers in *Archiving Performative Objects* project. Users rotated the head of the puppet via directional touch controls, controlled the pose of the right side and arm with the leading right controllers, and the left hand of the puppet with the second controller. The Vive mapping required to break down the control into such a two hand condition. This did not map onto the traditional one-handed set up for these puppets. As a result, the actual handling differed too much from the original “distance” condition and we excluded those puppets from the final study.

Future interfaces might potentially address such complications. However, in the preparation of our study we built on the existing limitation as well as on factors of actual puppet controls. Our designs were based on puppetry research, current VR interfaces, and the given puppets’ physical control schemes. They did not aim to use puppetry as a reference or abstraction but centered around applied puppetry practices as references for VR.

This resulted in a media-specific remediation of the existing puppet controllers that still map onto the behavior of the traditional puppets. For the string/ marionette condition, this meant that users grabbed and manipulated virtual controllers that, in turn, affected the puppets. The size and shape of the virtual controller crosses (as seen in fig. 3) reflected the actual size of the controllers of the physical puppet. The length of the strings reflected the actual length of the physical strings. The distance factor was kept as close as possible to the given original. Grabbing was performed by reaching with the Vive controller into the object (e.g. the rod or the manipulator cross) and pressing the trigger button. This attached the virtual control mechanism to the Vive controller and allowed the user to manipulate the corresponding puppet. Pressing the trigger bottom either allowed to pick up a second control or drop the current one.

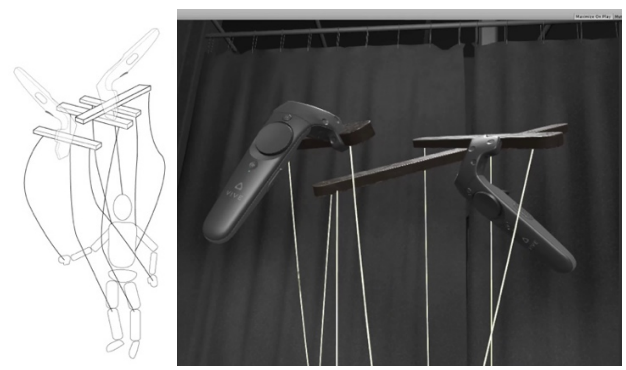

Figure 3: Marionette mapping example with virtual manipulator being controlled via the Vive controllers.

The same applies to the use of the rod controls (see fig. 4): the user would grab the digitized rod to control the Wayang Golek puppet. The Vive controllers granted access to the digitized control mechanisms of the digital puppets. For a direct manipulation puppet, that would be operated directly by grabbing on to the object, the VR controls equally allowed users to seize the object directly and move it. Individual puppet designs and their mappings have been discussed in earlier work [20] and will not be outlined here in detail.

The following study did not investigate the differences between different puppet interfaces but instead introduced four different puppet mappings in successions to every participant. Although the mappings were different between the four main puppets tested, they all followed the same Kaplin-inspired design principle of distance.

Figure 4: Wayang Golek puppet during user testing in simulated performance/ rehearsal conditions, including props, stage, and audience seating.

4 Study Design

The user study for *Archiving Performative Objects* included four different puppets – each selected from a different puppetry type. All four puppets were faithful 3D reproductions of existing archival ones selected from the *Center for Puppetry Arts*' collection. The VR versions offered individual controls based on their actual physical control schemes. During the study, all participants would control a direct manipulation object, a shadow puppet, a rod puppet, and a marionette – in that order.

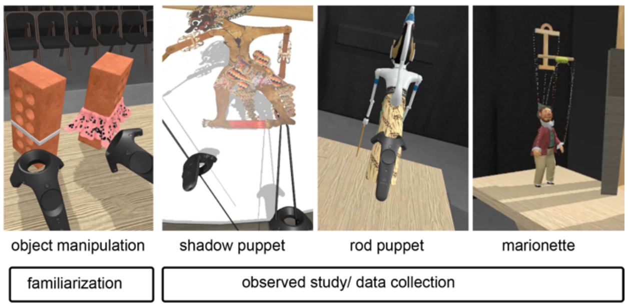

Figure 5: Successive testing: object manipulation, shadow puppet, rod puppet, string marionette.

The object manipulation stage served to familiarize participants with the interaction condition. Participants learned how to grab and conduct basic manipulations with the Vive controllers. This introductory stage was followed by a shadow puppet (based on a Wayang Kulit puppet), a rod puppet (based on a Wayang Golek puppet; see fig. 4), and finally a marionette (based on the Kasper puppet in fig. 1). Interaction times varied, but the VR encounter was limited to a maximum of 35 minutes for each participant. Starting with the shadow puppet, participants were asked to enact a basic scenario to motivate participants to create simple expressions with the puppets at hand. To further emphasize the performance condition, the VR tests were performed on a virtual stage modeled after one of the theaters of the *Center for Puppetry Arts*. The tasks in the scenarios were kept simple to encourage typical puppet manipulation (moving across stage, navigating around obstacles, interacting with props). They also were presented as a simple continuing narrative to allow for coherence throughout.

4.1 Set Up

The study focused on comparison between two different groups: puppetry experts and non-experts. Its goal was to explore possible differences between participants in their acceptance and assessment of the puppetry controls. Our hypothesis was that any interaction by expert puppeteers with the virtual puppets would be at least partially informed by their pre-existing knowledge of puppet manipulation. Depending on their acceptance of the VR interfaces, this would either lead to an expertise-based rejection of the interfaces as they failed to find the same finesse of controls; or a supportive endorsement as a new expressive opportunity. In either case, we expected differences in their assessment from non-experts that would help us to assess creative opportunities inherent in puppetry interaction designs. In comparison, the non-experts served as a control group with no prior practical knowledge of these techniques. The null hypothesis would be expert and non-experts report the same evaluation in the TLX and the CSI.

Tests were conducted in a 5x5m set up (limited by the sensing range of the HTC Vive) located in the lab of the Digital World & Image Group. Participants were first presented the consent form and informed about the project. They received a coded number used to anonymously track their questionnaire feedback. Each participant filled out a demographic questionnaire before the actual intervention. Then, they continued to the VR prototype. During the VR experiment, a participant would put on the Head Mounted Display (HMD) and hold the two controllers of the HTC Vive system. Participants received basic tasks based on puppetry movements that were contextualized in a simple narrative to perform. The prompts encouraged participants to engage with the puppet to perform typical manipulations such as walking, turning, bowing, or interacting with props on the stage. Each condition was set up as a continuation of a continuous basic storyline to enact.

Each virtual puppet offered its own control mechanism but they all followed puppetry traditions as outlined above. The controls grew in complexity as the participants turned from one puppet to next: from object-manipulation (which was used to familiarize users with the set up), to shadow puppetry, to rod puppetry, and finally to a virtual marionette (see fig. 5). This provided an increase in difficulty as well as a coherence between puppets. Performances were recorded within the VR world as well as participant's physical interactions.

Each participant had a short break after the VR experience to avoid possible mental stress. Then, each participant filled out two post-questionnaires (NASA TLX and CSI). Finally, participants took part in a concluding feedback and review session that was video recorded. All questionnaires were coded by numbers and anonymized.

4.2 Demographics

The expert group was recruited from local and national experts with extensive background in puppetry practice. Three participants of that group had 40 or more years of experience in puppetry practice. The demographic questionnaires also showed that the expert group population (n=9; m=5; f=4) was overall older (mean = 52.5 years) and significantly less experienced in VR and real-time 3D. Experience in VR was assessed by asking about familiarity with specific VR or VE set ups (e.g. Playstation VR or 3D modeling).

The non-expert group was recruited locally from students as well as visitors to the unit. The professional background of non-expert participants differed widely with "design" as the most mentioned field (4 participants). None of these group members had any previous experience in puppetry.

Participants in the non-expert group (n=9; f=7, m=2) were younger (mean = 34.2 years) and significantly more experienced in 3D design, VR, and real-time virtual worlds.

Gender distribution in the participants' groups was not balanced but we did not observe any impact of that differentiator. A more consistent measure was the lack of VR experience among older participants in both groups. However, this paper will not elaborate on the age differences in regard to VR. The focus will remain on a differentiation between levels of expertise. Recruitment and study design focused on this variable and the groups' sizes were too limited to allow an age-related secondary analysis.

4.3 Data Collected

The following data was collected: demographic data (via paper questionnaires), video recordings of the physical and the digital performance (via screen capture), observations in the form of field notes by the researchers, NASA TLX (Task Load Index) test (via paper questionnaire), CSI (Creativity Support Index) test (via digital questionnaire), and video recordings of final discussion and debriefing sessions. The video recordings of the VR performances were collected to identify possible design problems and glitches of the VR interface. They were intended as check for possible no-win condition and glitches that would render the entire test impossible, such as a puppet model that would consistently fail to work. While we experienced individual glitches, no persistent failures emerged during the test that would have stopped the VR performance. All participants managed to interact with all the virtual puppets and performed the given basic storyline.

Final debriefings were short, structured interview to provide qualitative feedback from the participants. The main quantitative data were the NASA TLX and the CSI. The NASA TLX was given as a paper questionnaire, data were transferred onto a summarizing Excel sheet and analyzed. The NASA TLX test is designed to assess interface feasibility in regard to necessary workload factors.

In addition, the CSI was deployed to focus on creative engagement with the particular interface/ device. The test was applied as a digital questionnaire that provides summarized values automatically. Both tests are widely used in Human Computer Interaction to evaluate digital interaction design and interface functionality.

4.4 Results

All 18 participants succeeded in manipulating the four different puppets throughout the test. Some technical glitches remained, especially regarding the puppets' physical collision behavior, but they affected all participants' interactions equally and did not prevent any participant from completing the study. The VR interface worked stable throughout and no participant had to interrupt the test for technical reasons. There were no cases of VR infused nausea or discomfort.

4.4.1 NASA TLX

The summary of the NASA TLX showed no differences between experts and non-experts in their perception regarding difficulties in handling the interface. Experts summative TLX mean was 15.2 and non-expert's mean TLX was 14.3.

The summative values are the combined result of 6 main categories tested in the NASA TLX questionnaire: mental, physical, temporal demand, effort, performance, and frustration. When taken apart, most of these values remained comparable between the two populations. Two differences are the higher value of the "mental demand" dimension among experts (experts 3.77 vs non-expert 2.55) and the higher value of "frustration" among non-experts (experts 1.72 vs non-experts 2.77).

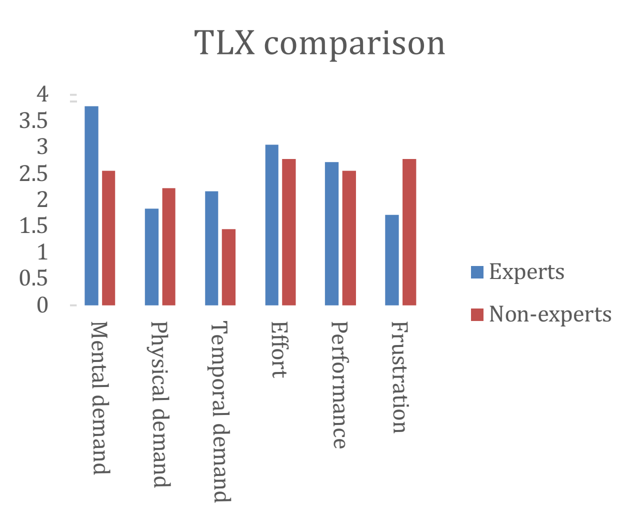

Figure 6: NASA TLX dimensions broken down between groups.

4.4.2 CSI

The summative CSI scores show an almost perfect balance of experts and no-experts (experts = 62.67 vs non-experts = 64.85). These initial summaries included the "collaboration" factor, which will be discussed further below.

While the overall CSI score distributions were comparable between experts and non-experts, their distribution range differed widely with the experts displaying a much wider range than the non-experts.

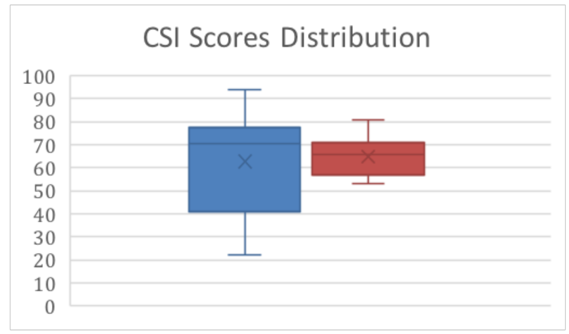

Figure 7: CSI score distribution between experts (mean= 62.67) and non-experts (mean=64.85).

The CSI test uses six different factors: collaboration, enjoyment, exploration, expressiveness, immersion, and results worth effort. It breaks these down for analysis in two different ways. The average *factor counts* indicates the importance that participants assign to specific components. It is assembled from a 15-question comparative section of the CSI test.

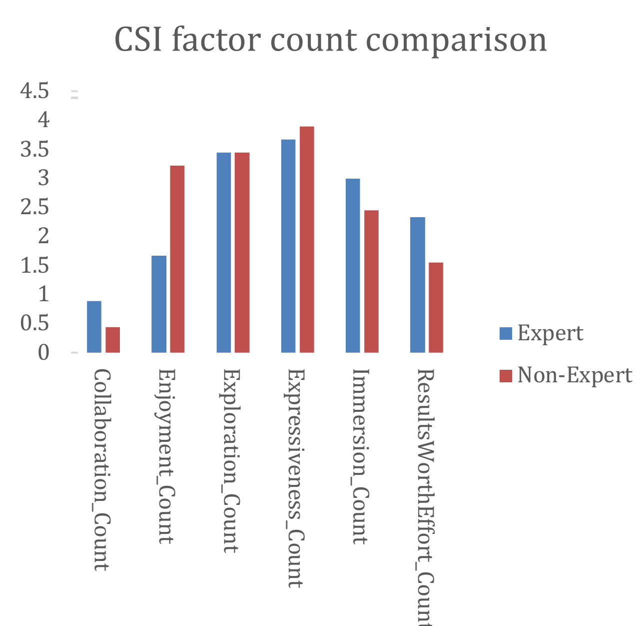

Figure 8: CSI factor count comparison between experts and non-experts (max = 10).

Both groups report comparable CSI factor count results. The main difference is in the "enjoyment" factor (experts = 1.66 vs non-experts = 3.22).

The second dimension in which these six CSI factors are captured is through a ranged assessment how strong a particular factor was perceived during the interaction. This *factor average* dimension for a CSI value is recorded and combined into cumulative values.

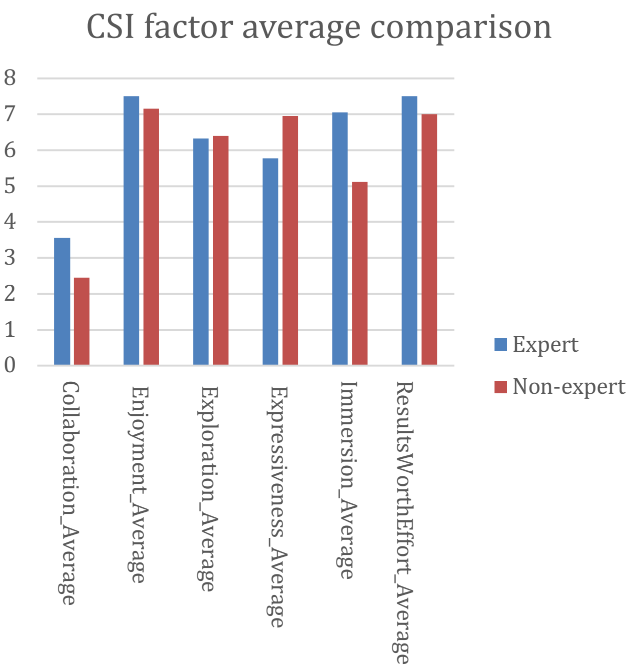

Figure 9: CSI factor average comparison between experts and non-experts (max = 10).

The single notable differing assessment in the average factor summary is the higher "immersion" value noted by experts (7.05) in comparison to non-experts (5.11).

5 Discussion

A key question of the study regarded the perceived creative range of a VR puppet interface between different populations. Thus, the first question is whether the creative options perceived were of any relevance to either group. This can be measured with the CSI scores. The mean CSI scores for the system were 62.67 for experts and 64.85 for non-experts. Any system below a CSI value of 50 would be considered severely lacking necessary creative options [21]. These initial values barely support the argument for a creativity supporting interface. However, the relatively low initial scores are due to the inclusion of the "collaboration" factor in the equation. The system had no collaborative features and thus received low ratings in this regard. Adjusting the CSI overall values to exclude the "collaboration" factor (with adjustment of one outlying expert value) leads to more favorable 71.55 among experts and 76.13 among non-experts.

We interpret the higher CSI values among the non-experts as a sign of their higher expertise in VR interfaces. The demographic questionnaires showed a higher VR expertise among the non-experts than among the puppetry experts. This reflects Cherry and Latulipe's hypothesis that "the CSI will be more affected by the expertise participants have with the tool than by their domain expertise; however, that is left for further research." [21] Non-experts were more familiar with the tool (VR) and less with the domain (puppetry). At the same time, the wide range among puppeteer experts factor distribution (fig. 7) indicates challenges with the current interface on the one hand, as well as, at times very high, creative engagement on the other.

We also interpret the main difference in *CSI factor averages* (fig. 9) as a result of different levels of expertise with VR technology. Non-experts reported less "immersion" (5.11) than puppetry experts (7.05). The stronger report on "immersion" among puppetry experts is understood as a result of their limited – sometimes first – experience of VR as technology.

Within the *CSI factor comparison* (fig. 8) "expressiveness" stands as the most noted among experts (3.66) as well as non-experts (3.88). This indicates that independently of levels of expertise in the puppetry domain, both groups agreed that the puppetry interfaces provided a useful expressive range.

The study's second core question regards the value and usability of the interface as such and how it was perceived by the study participants. This is reflected in the TLX data. One surprise in these data was the higher TLX factor of "mental demand" among experts (3.77) vs non-experts (2.55) (see fig. 6). Originally, we had expected that experts would have less problems to engage with the virtual puppets, being familiar with their original control mechanisms and simulated operations. They might have to adjust to the VR conditions but as the interactions were new to both groups, we had not anticipated these results. To explain this difference in more detail, we turned to qualitative feedback from the experts during the final evaluation interviews.

On the one hand, the mismatch in "mental demand" seems to be based on unfulfilled expectations among the puppetry experts. The puppets mimic the physical control mechanisms but clearly do not fully reproduce their conditions. P3 noted that "There was no sense of holding, touching, or weight, but there was that visual richness." More specific to individual puppets, P2 mentioned "I am used to cheating by pulling on strings" of the marionette puppets. Individual strings were not accessible in the system, nor did they provide the kind of physical force-feedback noted by P3. Thus, the limitations of the virtual system in terms of force feedback, physics simulation, or lack of higher fidelity caused a mismatch. This break of expected behavior might have caused some irritation and higher mental demands.

Such expectations were also noted on a broader level of the puppets as cultural artifacts. One VR puppet was a Wayang Kulit puppet. As multiple participants (P4, P5) noted, these puppets are traditionally played with puppeteer, the dalang, sitting. Physical performance set ups include a large log in front of the performer into which the rods of these shadow puppets can be fixated. Our VR system did not provide these particular conditions. While they expected to sit down to play the puppet, the system let them stand instead. This might cause conflicts with any embodied tacit knowledge the puppeteers brought to the experience and thus demand higher mental demands to adjust. Another puppet was modeled after a Wayang Golek design (see fig. 4) usually played with a hand reaching into the puppet and thus shaping the inner body and the clothing. As P2 noted "I assumed the fabric to bent" but due to limitations in the real-time rendering of cloth, that was not fully implemented. Breaking such expectations might have called for more mental adjustment among the experts, who expected different conditions.

At the same time, multiple puppeteers emphasized that the difference of the digital puppets in comparison to the physical ones was engaging in itself and inspired further exploration.

"As a puppeteer, when I first look at a puppet, I pick it up and I explore what it can do. I find myself doing the exact same thing in this [VR] environment, which is very powerful and healthy to me. Like picking up any real puppet for the first time, I have the same sort of exploratory experience. I thought that was really powerful. that part of it was very strong for me." (P7)

Thus, the higher mental demands might be further increased by the activation of such an exploration of the puppets as fully fledged expressive entities in their own rights. As P5 mentioned, it was about "exploring how it was different from real puppets." The limitations that caused the initial defamiliarization also stimulated new explorations. This could further explain the higher mental demands that were recorded among expert puppeteers as this requires a dual adjustment away from established expectations and towards the experimentation with the new. This might also explain the lower CSI factor in "enjoyment" weighing among experts (1.66) vs non-experts (3.22) (see fig. 8). This difference indicates that puppet experts expected less "enjoyment" from the interaction, possibly because they approached it more as a professional performance situation. In comparison, the non-experts saw the puppets more as objects to enjoy and play with – based on their experience as puppetry audiences not performers.

In summary, the summative values of experts and non-experts in both CSI and TLX were comparable. However, the differences between the two populations become clearer in the details of the two data sets and in cross-referencing qualitative feedback. As VR interfaces, the puppets were more familiar to non-experts, due to their higher pre-existing VR literacy, but they remained play elements. For experts, the interfaces were more demanding but also established the virtual puppets as expressive objects in their own rights.

6 Conclusion

This paper outlined the design and implementation of multiple puppets that followed a basic interaction model grounded in the "distance" factor introduced by Kaplin [19]. It was realized through detailed 3D object capture of traditional puppets and an indirect control mapping. The VR controllers were used to manipulate virtual controllers, that in turn affected the 3D puppets. The subsequent study tested for feasibility and creative range across different puppet-based conditions to investigate effects between two groups of participants with different levels of expertise in puppetry.

A comparative study between different puppetry conditions, such as marionette vs hand puppet, might add additional detailed dimensions. Yet, such a differentiation was not the goal of this study. Instead, it asked whether puppetry interfaces *as such* might be a creative venue for interaction design in VR and whether such a value might be traced between different groups of participants depending on their level of expertise.

While the study's limited number of participants (n=18) allows only indicative results, it highlights the expressive value of such interfaces. Their efficiency is acknowledged by both groups and independently from their level of expertise in VR or puppetry (as reflected in the CSI factor count results).

Puppetry experts reported more mental demands to operate the system. We interpret this as an activation of their expertise in relation to the interfaces as cultural expressive domain artifacts. On the one hand, their expectations regarding the simulated puppets were not fully met. On the other hand, these broken expectations led experts to actively and successfully explore new opportunities of the virtual puppets using their established puppetry skills. This indicates the presence of such opportunities and a possible future range for puppet-based interfaces in VR.

We see a variety of new approaches to VR interaction design, ranging from user embodiment of single characters to control of multiple characters at the same time, either through direct or indirect manipulation. Our design focused on the "distance" component but additionally incorporating the "ratio" component might allow designs of single objects controlled by multiple users simultaneously. One example for such a control scheme can be found in the videogame *Octodad* (Young Horses Inc. 2014) that allows multiple players to control a shared game creature. However, in this case no VR condition is supported and interaction is purposeful chaotic. Procedural animation provides another opportunity for a hybrid "ratio" control scheme. Here, user and system can collaboratively share control. Modern game and virtual world applications already provide forms of such control sharing. They show avatars that may react/ animate differently depending on the condition or location in the game world. Contextual interfaces, here, mean shared animation control – a feature that demands careful balance.

A second opportunity for further development is inspired by the string-based controls. As noted in the expert feedback, marionette systems allow for increasingly fine-grained controls. Instead of controlling the movement using the main cross manipulator, puppeteers can pull individual strings for certain effects. Following the "distance" criteria, this resembles an ever "closer" control format. Such a shift would support interaction design for layered actions, e.g. from a movement to an individual expression or from the positioning of a virtual tool to its specific application. Such layering would benefit further from force-feedback or tangible interaction designs that allow immediate responses of the virtual object.

Puppeteers can be seen as expert analysts, experienced game or interface evaluators, with an awareness of possible expressive opportunities that elude most HCI designers. As they explored the interfaces anew, the puppeteers of this study reached toward novel expressive means in VR. They explored the design space through their practice.

Ultimately, there are countless approaches to technical puppet construction (e.g. [22]) and no single language of puppetry. Thus, the collaborative exploration suggested here will not realize in fixed frameworks or matrices. However, puppeteering as practice is well-established and its communities remain centers of innovation and expertise. To combine the two will be a meeting point of two different creative practices but – as past projects as well as this one have shown – well worth the effort.

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