Germane Elements for the Evaluation of Transitional Interfaces

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As Mixed Reality (MR) and Transitional Interfaces (TIs) become more common, evaluation needs to step up to the task. In this position paper we elaborate on elements from current research in MR and cognitive psychology that appear to be relevant for evaluating TIs. The four factors considered in this position paper are presence, physical discomfort, spatial orientation and cognitive load. For each of these aspects we discuss the meaning, their relevance for TIs and how they can be evaluated.

CCS Concepts: • **Human-centered computing → User studies**; *Laboratory experiments*; HCI theory, concepts and models.

Additional Key Words and Phrases: user evaluation, presence, simulator sickness, spatial orientation, cognitive load

ACM Reference Format:
JUDITH FRIEDL, JANINE MAYER, and CHRISTOPH ANTHES. 2021. Germane Elements for the Evaluation of Transitional Interfaces. In *ISS'21 Workshop Proceedings: "Transitional Interfaces in Mixed and Cross-Reality: A new frontier?", November 14, 2021, Łódź, Poland*. ACM, New York, NY, USA, 7 pages. https://doi.org/10.1145/10.18148/kops/352-2-1l0cten6mk0j8

1 INTRODUCTION

The four elements we deemed relevant for the evaluation of TIs, were selected from current research in MR and cognitive psychology. The first on, *presence*, is a common topic in Virtual Reality (VR) research, where numerous different approaches exist for its classification and evaluation [42, 46]. Although this phenomenon is linked to the users being located in an immersive virtual environment (VE), it has already been deemed interesting for evaluating TIs [16]. After all, the design of TIs could play an essential role in furthering presence in stages leaning towards virtuality on the Reality Virtuality (RV) continuum [28], such as VR and Augmented Virtuality (AV) [44].

The second element we chose is *physical discomfort.* In VR research, symptoms that fall into this category are mostly measured to report simulator sickness or cybersickness. However, especially in the context of TIs this aspect goes far beyond administering a questionnaire. In this context, users may experience different symptoms of physical discomfort, such as ergonomic issues [7], depending on the stage of the RV continuum they are currently located at. In some cases, transitioning to a different stage could also mitigate some of the experienced symptoms.

As a third element, we chose *spatial orientation.* This aspect is especially interesting for TIs since VEs are often used for spatial training [12]. There, the transition itself may have an impact on correct estimation of distances or on the users ability to locate themselves or objects in the (virtual) room [24]. The last element is *cognitive load*, which is rooted in theories on the way the human brain processes information [55, 56]. From there, it made its way to several other research areas such as Human Computer Interaction (HCI) and Information Visualization (InfoVis) [20]. For research in TIs, it will be interesting to see how they affect cognitive load, especially in the context of visual analytics [36] and educational technology [14].

2 ELEMENTS FOR EVALUATING TRANSITIONAL INTERFACES

Since TIs bridge the gap between reality and virtuality [3, 36], they are inherently linked to the concepts explained in detail below.

2.1 Presence

Presence was originally described as the tendency of people to react to virtual sensory stimulation as if it was really happening in the physical world [38]. It is a human's reaction to immersion, which in turn is a description of characteristics of a system, such as display resolution [49]. However, later Slater redefined both of these concepts due to confusion in definitions and introduced two new terms to describe this phenomenon. What was formerly encompassed by the term presence, he redefined as Place Illusion. Precisely, it is now defined as *"the strong illusion of being in a place in spite of the sure knowledge that you are not there"* [48]. Additionally, Slater introduced Plausibility Illusion as *"the illusion that what is apparently happening is really happening (even though you know for sure that it is not)"* [48]. Nevertheless, lots of research is still concerned with the term *Presence*, so we stick to this term in this position paper instead of the later introduced term of Place Illusion.

There are different ways to assess presence. The most common of which is the use of questionnaires such as the Slater-Usoh-Steed Presence Questionnaire [51], the Witmer & Singer Presence Questionnaire [61] and the IGroup Presence Questionnaire [41]. The latter one combined several earlier questionnaires, including the other two mentioned above. However, Slater [47] argues that presence cannot be measured reliably by post-hoc questionnaires, since they cannot rule out that the measured "presence" is not just created through the act of asking about it. In order to find individual differences between subjects, Witmer & Singer suggest to administer the Immersive Tendencies Questionnaire (ITQ), which is designed to assess each individual user's overall tendencies of immersing themselves, before the actual task [61]. Apart from questionnaires Slater et al. [49] also mention behavioural and physiological ways to measure presence, as well as an approach that measures breaks in presence instead of presence itself [50]. Moreover, they claim that for true measurement of presence it is necessary to evaluate it against ground truth [49], which means a comparison of the user's observed reaction in the VE to the expected reaction in a real environment. Therefore, there is not yet a universally agreed on procedure to evaluate presence, although the use of questionnaires might be the most common one. Nonetheless, due to the suspected influence of post-hoc questionnaires on the measured data itself, it seems like a focus on physical and observational measurements would make sense when evaluating presence. Another interesting approach for a subjective measurement of presence could be to interview the users during the task. However, the interviewer would need to be present in the immersive environment themselves, e.g. by an avatar representation or by using AV, so the evaluator doesn't alter the user's experience of presence [13].

Presence is a crucial aspect for users in order to embrace the VE they are currently in. The design of TIs could therefore be essential for furthering presence in such environments. In terms of research questions for presence in TIs, it will be interesting to explore whether the transition itself results in a break in presence, as described by Slater et al. [50], and if certain transition techniques further or inhibit the experience of presence. For example, portals [31] could further presence when compared to a simple appearance/disappearance [45] as it may seem more plausible to the user.

2.2 Physical Discomfort in VEs

When looking for research in the area of physical discomfort induced by VEs, the most common topics are simulator sickness and cybersickness. Simulator sickness describes a number of symptoms, such as nausea and disorientation, that can occur during and due to an immersive experience. Since similar symptoms have also been observed in VR, simulator sickness is often used as a synonym for cybersickness. However, Stanney et al. [52] found that there is a number of differences between these phenomena. For example, they mention that oculomotor symptoms are predominant in simulator sickness, whereas, in cybersickness disorientation was found to be predominant. This difference in symptoms is partially caused by different hardware used for the presentation of the experiences.

Nevertheless, both phenomena are often measured using the Simulator Sickness Questionnaire (SSQ) [23], which provides scores for each of these symptomatic groups. The SSQ is still considered to be the golden standard for measuring cybersickness [8] as well as simulator sickness. Yet, Hirzle et al. [19] argue that the SSQ is often used in VR to assess general discomfort, while mainly considering symptoms of motion sickness. This is due to the SSQ being developed based on the Pensacola Motion Sickness Questionnaire [23]. While this still is an important aspect that can be caused by VEs, this leaves out other elements, such as digital eye strain and ergonomics [19]. Cybersickness can occur in any immersive system, however, the level of immersion seems to be linked to the extent to which cybersickness is reported, which was found both in AR [21] and in VR [27].

For TIs, it is especially interesting whether the transition between different stages on the RV continuum mitigates some of these symptoms. For example, due to the link between reported frequency of cybersickness and the level of immersion, it may help a person experiencing symptoms of cybersickness in VR to transition to AR.

2.3 Spatial Orientation

Spatial orientation is the user's sense of position and orientation in the VE [5]. To keep track of that, humans use visual cues that are often more sparsely available in VEs than they are in reality [5]. VR and AR have often been investigated as tools to train the user's spatial memory as an addition or alternative to training simulations in the real world. For example, Bliss et al. investigated the use of VR for training firefighters [4], Auer et al. investigated the use of VR for cockpit familiarization of pilots [2] and Dünser et al. investigated the use of AR for spatial training using a 3D geometric construction tool [12]. A premise for using these technologies for spatial training is that people can correctly estimate distance in these VEs. However, users seem to underestimate distances both in VR [24, 35, 58–60] and in AR [54].

Spatial orientation is typically evaluated using controlled experiments with multiple conditions, such as different travel techniques [6]. Users perform a task either in a between-subjects design, where each user completes tasks only in one condition [33, 53], or in a within subjects design, where each user completes tasks in all conditions [9, 29]. As a quantifiable measure, the task error is measured for each participant and condition [6, 34]. For example, when users are asked in the task to point into the direction of a previously seen object, the task error is the angular error between the direction the users pointed to and the position of the real object. Another common measure for controlled experiments is the task time [5, 33]. In order to take general spatial ability into account as a confounding variable, Suma and Hodges [53] used the Guilford-Zimmerman Aptitude Survey Part 5: Spatial Orientation [17], which revealed an uneven distribution of spatial ability between the different groups. Finally, the collected measures are typically analysed for statistical significance using a suitable test such as an analysis of variance [9, 34] or a Friedman test as the non-parametric equivalent [39].

For TIs, spatial orientation is relevant since Cross-Virtuality (XV) [36] applications are already explored as a tool for spatial training [22]. Therefore, it is necessary to look at the effects of TIs on the spatial ability of users. For instance, a transition where the real world slowly fades into a VE [31] could be more effective than a portal transition when it comes to preserving the user's sense of position and orientation.

2.4 Cognitive Load

Cognitive Load is a concept from cognitive psychology that was first described in the late 1980s by John Sweller as a theory of learning and is based on the assumption that the working memory has only limited capacity [55]. The term cognitive load itself describes the demands on the working memory storage and information processing [40]. Cognitive load theory (CLT) distinguishes between three types of cognitive load: intrinsic, extraneous and germane cognitive load. Intrinsic cognitive load is based on the inherent complexity of the learning matter, while extraneous cognitive load describes complexity that is added by a non-ideal form of presentation of the learning material e.g. unsuitable visualisations [56]. Reducing extraneous cognitive load is therefore the main concern of CLT. Germane cognitive is not itself another source of cognitive load. Instead, it describes the working memory resources that are available for dealing with the intrinsic cognitive load. Therefore, germane cognitive load is low when extraneous cognitive load is high, since there are only little resources available for dealing with the learning matter, i.e. the intrinsic cognitive load [56].

There are different methods to assess cognitive load with the most common being self-reported stress or mental effort using simple scales [26]. These scales are administered after the task and provide a simple value for cognitive load and have the advantage that it only requires about 30 seconds to conduct them [57]. However, such simple scales do not provide any explanation on *why* a specific value was reported. Moreover, their validity and reliability are based on the (questionable) assumption that users can retrospectively reflect on and report their cognitive workload [26]. The most common example of such simple scales for cognitive load is the NASA Task Load Index (NASA-TLX) [18, 32, 37].

Beside subjective measures, there are several approaches of objective measures. One method that is gaining attention is eye-tracking, which is based on the assumption that parameters such as pupil size and eye movement are reflecting information on cognitive activity [26] with numerous studies exploring this topic [11, 15, 62], including an approach that combines several of these parameters by using a structural equation model [30]. However, there is still more research required to prove the effectiveness of such techniques [57]. Moreover there are also several approaches using physical measures such as galvanic skin response (GSR) [43], electroencephalography (EEG) [1] and many more [26].

As a theory for learning CLT has found its way into HCI and InfoVis [10, 20, 25, 62] where it has become a valuable metric for evaluation. This could also translate to TIs, as cognitive load provides a measure for the demands of a system on its user's working memory. At this point, it is still unknown what effect transitions have on cognitive load. For example, TIs could increase cognitive load as the user has to keep more information in the working memory.

3 CONCLUSION

Overall, there are several measures from current research in MR and Cognitive Psychology that will be interesting to explore in research on TIs. Presence (or place illusion and plausibility illusion [48]) is critical for users to fully immerse in mainly virtual environments. In order for users to focus completely on the VE, it is necessary to reduce physical discomfort which should be considered from a holistic point of view. Furthermore, TIs should be considered in terms or their influence on spatial orientation, so XV systems can be usable tools for spatial training. Finally, cognitive load provides an interesting measure for evaluating the use of TIs for tasks were a large amount of data needs to be processed, such as visual analysis.

4 ACKNOWLEDGMENTS

This publication is part of the X-PRO project. The project X-PRO is financed by research subsidies granted by the government of Upper Austria.

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