Content knowledge and thematic inertia predict virtual presence

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Abstract

This paper informs the debate between the impact of content and form factors on presence. From cognitive principles, we predict that the content of a VE will affect presence by interacting with expectations held by the user. Furthermore, a particular cognitive tendency (thematic inertia), should facilitate the effect of the expectations. A sample of 461 users of desktop based flight simulations was measured on ten predictors, including degree of simulation related content knowledge (generalized and specific knowledge), thematic inertia, as well as controls for age and immersion/display factors. The ITC-SOPI was the dependent variable. The data suggest that content factors explain almost as much presence variance as form (immersion) factors. As predicted, thematic inertia is a reliable predictor. Also, the degree of generality of content knowledge predicts presence (with knowledge of the specific content being an inverse predictor). This strongly suggests that the degree to which a simulation is able to match the expectations of its users is an important element of the presence experience.

Keywords--- Presence, Content, Cognition, Theory.

1. Introduction

A large body of literature, both theoretical and empirical, exists to support the notion that presence is a function of display and immersion related variables (see [1] for an extensive review). More recent examinations into the role of content related factors on presence, however, remain controversial. The debate, which could be named the content-form debate, was most explicitly delineated by Slater [2]. In that paper, Slater makes a strong distinction between *spatial presence* (the conventional concept that a virtual place is experienced as if it were not mediated), and a host of concepts, such as engagement and involvement, which have become incorporated into definitions of presence by others (such as [3]). By analogy, he argues that presence comes about by the form in which information is presented to the subject; interest, involvement, and so on are brought about by the subject's relationship to the content – therefore, content related factors are considered as not determining presence. The argument that form and content are separate in media has existed for some time; for instance, during the 1960s discussions existed about whether television (a new medium at the time) was able to deliver novel types of content or not [4]. In general, media theorists consider form and content to be theoretically separate concepts [5]. Logically, they are neither equivalent nor necessarily related. However, there is not much empirical evidence to suggest that, from a user perspective, they might not be related, causally or otherwise. In the presence literature, the role of content has generally been discussed theoretically only (for instance, [6, 7, 8]). The consensus seems to be that for presence to occur, the environment must make some sense or contain some meaning for the subject; and it is the content that provides that meaning. For example, in a factor analysis of eight presence measures, [9] found that the factor *drama* (the degree to which the virtual environment presents a story in which events unfold in a meaningful, predictable way) ranked 4th out of 8 extracted factors, and had an eigenvalue greater than 3 [9]. Such findings are quite suggestive that the content of a VE does have a role to play in the presence experience. Given that little empirical work has been done on this problem, and given that it is a focus of attention in presence theory, it is worth making a detailed examination of the extent to which content factors play a role in presence.

It is difficult to understand how content may affect presence without some theoretical framework. A recent development in presence theory, expressed in [7] and [10], is that presence does not occur from perceptual data alone (as an illusion such as vection does), but rather is constructed from both perceptual and conceptual data by the subject. In this view, the percepts can only be constructed into an experience of space in the correct cognitive context [10]. This context is likely to be affected by two factors: temporary effects such as priming [11, 12], and more permanent effects associated with knowledge of a particular theme [13]. The impact of these temporary effects on presence have been empirically investigated to a limited degree [11], but the long term effects remain in the domain of theory.

One reason why content may not have attracted a great deal of research attention is the difficulty of working with it as an operationalized variable. Are there factors along which different contents can be compared? Is there a way to measure the impact that a particular content area will have on subjects? We believe that for the purpose of examining its effect on presence, the particular content itself is not central. Rather, it is the examination of how the content is integrated and processed cognitively that might lead to viable research designs [10]. To quantify this degree of integration, one can, according to a schemata based theory, measure a participant's knowledge of the content [14, 10]. How this existing knowledge then interacts with the VE display during the mediated experience can be usefully modeled by thinking in terms of user expectations. As the user begins the experience, the VE content cues a slight activation of particular schemata. If the content is well integrated, then that activation will spread efficiently though the user's semantic knowledge networks, leading to expectations of subsequent experiences in the VE [15, 13]. If the VE matches these expectations, one can expect a coherent cognitive construction of the environment [10]. If the VE fails to match those expectations, then an impoverished presence experience will result [16, 10]. If one accepts this explanation, then one can categorize the user's knowledge in terms of the types of expectations it will lead to – detailed knowledge will lead to highly specific expectations, which will be hard for the VE to match; generalized knowledge will lead diffuse expectations which should be easier for a VE system to match [16]. Therefore, one can expect an expert in a particular content area to find simulations of that content to be largely unsatisfactory, unless the simulation's content has been designed to a high degree of fidelity. They would constantly notice errors in the simulation, and would therefore have reduced presence experiences. On the other hand, a novice in that content area, with less content knowledge would find the same simulation satisfactory due to having only very general expectations for that content, and might therefore experience more presence. This is analogous to the well-known "uncanny valley" phenomenon found in simulations of humans [17]. Almost all people have extremely detailed knowledge of the human form (albeit largely implicit), which leads to very specific expectations. A simulation must be of an extremely high degree of fidelity to match such an expectation; indeed, most contemporary systems fail at this task, leaving users largely unsatisfied by the simulation. Our model of knowledge, expectation, and simulation matching of these expectations can essentially be understood as a general explanation of the uncanny valley phenomenon, from a cognitive perspective.

That content could have an effect on the user's experience in this way seems plausible; however the questions of whether this effect is on spatial presence or other related factors, as argued in [2], and of the degree of impact that content factors have on presence are ones which must be addressed empirically. From this discussion, we can define three broad aims for this study:

1. To examine the role of content knowledge on the presence experience (both in terms of spatial presence and other related factors such as engagement). We will also examine if a difference of effect exists between general and specific knowledge.

2. To examine the relative importance of temporary content effects. This can be done by examining thematic inertia, a measure of the degree of cognitive integration of a particular semantic content area [12] and priming, the phenomenon where users engage in behaviors to prepare themselves cognitively for the VE experience [12]. However, we will examine these effects on a standardized presence measure, rather than using the evolutionary approach used in [12].

3. To provide some sense of the relative contributions of form related and content related factors, so as to shed some light on the content-form debate.

2. Method

To achieve these aims, we followed a relational design, preferring to collect a large sample of habitual VE users in naturalistic conditions over a controlled experiment using a smaller sample. We therefore used a large scale online survey of computer game players who play flight simulation games. We measured our sample on a number of content, cognitive and form/immersion variables, and used these to predict their presence during their last simulator session using the ITC-Sense of presence inventory (ITC-SOPI) [3].

2.1 Procedure

The study was advertised as a 'flight simulator gaming habits' study, and posted as an on-line survey. A number of web-sites were selected to advertise the study: These were either web-portals to the flight simulation gaming community (presenting news, downloads, etc. relating to the hobby), or web forum sites whose primary purpose is the discussion of flight simulation related topics. The site administrators of 10 such sites were contacted and asked to post a link to the study on their site. Of these, 7 responded (70% response rate). In order to provide an incentive for participation, Flight1.com, an on-line retailer of flight simulation products, was recruited as a sponsor of the study. They provided three popular flight simulator products as prizes for a random draw of subjects.

The subjects were provided with a URL for the study website. On entering the site, they were provided with information about the study (enough to meet the informed consent ethical requirement while reducing possible expectancy effects), and if they agreed to continue, were presented with instructions, and then the questionnaires. The subjects were first presented with our ten content, cognitive and control factors, and then were asked to report the title of the last flight simulator they played, and the number of days since that last session (the experience-measure delay). They were then asked to complete the ITC-SOPI with regard to that session. With the exception of not administering the ITC-SOPI immediately after the VE experience, we followed all the administration guidelines given by the authors of the ITC-SOPI. Once all the items were completed, the subjects were asked to fill in their email address for entry into the random draw (this information was not stored together with their actual data).

2.2 Sample

A practical sampling problem arises in content related research – what population has varying degrees of knowledge of one well-defined content area, for which there exists a virtual environment which implements that content area? We decided to turn to the population of computer game players who use flight simulation games. For this case, the content is well defined (aviation), and knowledge of it can be reasonably measured – by either asking subjects to report on their level of knowledge, or by examining their interest in other activities related to the content area (reading aviation books, visiting aviation web-pages, etc.) One can also determine if the subjects have generalized or specific knowledge with relative ease (see measures in 2.3 below). Also, the flight simulation playing population is large, and easily accessible; it therefore serves as a useful starting point for such an investigation.

A total of 503 responses were collected from flight simulation players (see section 2.1 above for a description of the recruitment procedure). Of these, 461 (91.6%) reported using *Microsoft Flight Simulator 2004: A Century of Flight* during their last simulator session. These were selected as the sample for the study. This was done to control for software platform cross users. In effect then, this is a self-selected, volunteer sample. The sample consisted of 100% men. One may be forgiven for assuming that this is a massive overrepresentation, but this gender distribution probably correctly represents this particular population; the flight simulation site AVSIM.com, in the 2003 edition of its yearly census of users, found only 2.6% of users to be women with a sample of 14,247 [18]. Of course, such a population precludes any investigation of gender effects. Due to this, we decided to exclude gender as a variable in this particular study. This decision has some justification - a recent review [19] which examined nine studies considering gender in presence, found a difference in only one of those studies. In terms of age, the sample was far more diverse; the mean age was 31.7 years, with a range of 12 to 65 ($s = 13.07$ years).

2.3 Measures:

The ITC sense of presence inventory (ITC-SOPI) [3] was used as the measure of presence. This questionnaire measures four factors of the presence experience: Spatial presence, engagement, naturalness and negative effects. These are defined as follows (from highest to lowest degree of variance explained):

Spatial presence: A sense of physical placement within the VE, and of interaction with the objects in the VE.

Engagement: A sense of psychological involvement and a tendency to enjoy the VE experience.

Naturalness: A sense that the VE is believable and lifelike, or realistic (this factor is also referred to in [3] as *ecological validity*).

Negative effects: Negative physiological reactions to the VE experience such as dizziness, eyestrain and headaches.

The ITC-SOPI is a particularly useful measure in that each of the factors provides a separate score for the experience. This effectively allows it to satisfy a number of presence concepts at once, effectively separating out spatial presence from the other factors. For instance, if one follows the presence concept presented by Slater [2], then one can simply consider the spatial presence factor of the ITC-SOPI. However, if one is sympathetic to the views of IJsselsteijn and colleagues (eg, [20]), then one can consider both the engagement and spatial presence factors. This flexibility, its suitability for use across any medium representing a VE, and its high degree of psychometric evaluation [3] makes it a particularly useful instrument for a large study involving home computer based flight simulation software.

Our second major measure is a questionnaire, developed for use in this study, containing ten content knowledge, cognitive and general control factors to be used as predictors (see table 1 below for a summary). The factors are defined as:

Thematic inertia: This is the same concept proposed in [12]. It is the tendency for a subject to engage in thematically related activities (e.g. reading about aviation, as well as playing aviation related games). In this study, we considered situations where non-simulation activities (reading a book, taking a real flight) led to either a desire to play a flight simulator, or the actual playing of a flight simulator.

Priming: This refers to subjects engaging in particular behaviors before playing flight simulations, so as to set a cognitive context for the simulation experience in some way [21]. We considered cases where subjects read aviation books, manuals, aeronautical charts, or engaged in similar activities immediately before a flight simulation session. We hypothesize that priming and thematic inertia are closely related, although this has not been specifically investigated. Thematic inertia is likely a tendency or cognitive style, while priming is one of the behaviors which expresses that tendency.

Factor with Number of items (Cronbach's alpha in brackets)	Sample item
Thematic inertia 5 (0.79)	"Reading about real world aviation or flight in a book, magazine or web-page makes me want to play a flight simulator."
Priming 5 (0.76)	"Before I play a flight simulator, I usually read an aviation/flight book, magazine, or web page."
Content knowledge 8 (0.63)	"I prefer to fly virtual flights around places which I have been to in real life."
Hobby cluster 7 (0.55)	"How many model aircraft have you built in the past year (scale models or radio-controlled)?"
Simulator mechanics knowledge 9 (0.76)	"Have you ever created an aircraft (exterior model, flight model, etc.) for any flight simulator?"
Presence management 8 (0.69)	"What size of screen/display do you usually play simulators with?"
Evaluation of simulator realism 6 (0.76)	"The experience provided by current commercial flight simulators is like the real thing."
Enjoyment 6 (0.68)	"I normally find playing commercial flight simulators to be a fun experience."
Experience-measure delay 1 (-)	"How many days ago was this last session?"
Age 1 (-)	"What is your age?"

TABLE 1: The ten content, cognitive and control factors used to predict ITC-SOPI scores

Content knowledge: This refers to knowledge of the actual content being simulated; that is, specific knowledge of the real places and aircraft being simulated. This factor allows the measurement of the influence of the fit between the simulation display and a specific expectation of the scene. This follows our model that the amount of information about the content held by the subject is likely to correlate with how specific the subject's expectations are (see the discussion in 1 above).

Hobby cluster: This is a measure of the degree to which the subject engages in other activities which are related to aviation, such as building model aircraft or reading aviation publications. It is of interest in this study because it represents generalized knowledge of the content being simulated, in contrast to the *content knowledge* factor, which measures specific knowledge.

Simulator mechanics knowledge: This factor considers the subject's knowledge of how simulation software works. Apart from measuring this directly as done by [12] (a method which may give rise to self-report biases), we further estimated it by using the number of modifications, add-ons or simulation content created by the subject - we assume that being able to create simulator content requires knowledge of how the simulation works. This factor can be used to control for information relevance, by contrasting its effect with the content relevant *content knowledge* and *hobby cluster* factors.

Presence management: This is the same factor defined in [12]. It represents measures taken to improve the immersion of the hardware platform, and of the user to reduce attention distracters. We expanded this factor to include the use of consumer grade simulation input devices (joysticks, control yokes, rudder pedals, throttle quadrants, etc.) which are widely available. These not only provide improved control for the user, but also act as passive haptic devices [22], as they mimic the shape of real aircraft controls. This factor represents our notion of a display and attention related factors. It also expresses some consensus of immersion and display factors identified as important in the literature (as discussed in 1 above).

Evaluation of simulator realism: This is a measure of how realistic the subject considers flight simulations to be, in general terms. Notice that we do not use this as a measure of the realism of the system, but of the *perceived* realism. This cognitive factor represents arguably the most abstract level of expectation. Subjects who rate a simulation as realistic are presenting an interpretation bias; we can thus infer, according to the constructionist concepts of [10] and [14] that subjects who score high on this factor are less likely to interpret simulation artifacts as detracting from the experience.

Enjoyment: This factor estimates how fun or enjoyable the subject finds simulations in general. This is an important control, as there is evidence to suggest that presence varies with enjoyment of the experience [23, 24]. Given that the subjects in this study use flight simulations for recreation, it is likely to be a factor. It is also possible that subjects who find the experience enjoyable would have a bias to overestimate their presence (the converse bias is also technically possible, but due to the self-selection of this sample, it is unlikely).

Experience-measure delay: As this study takes the unusual step of asking subjects to complete the ITC-SOPI with regard to their last flight simulation experience (see 2.1 above for the procedure), this factor was included to control for any possible memory or delay effects. The granularity of this measure was chosen as one day.

Age: This is a control for two factors: The possible natural covariance of age with cognitive factors (such as attention, spatial ability, etc.) due to aging, as well as for the possibility of a general correlation between age and presence (as reported in [25]).

2.4 Models and analysis strategy

In this type of research, it is usual to create a single model from a set of predictors, and then evaluate the usefulness of that model by examining its fit to the data (as was done in [12]). However, we propose to go one step further by comparing the fit of two models to each other: The first will be our model including three sets of factors: display and attention factors (form related); content and cognitive factors (content related) and general control factors. The second model will be a reduced, conservative model including only display and attention factors (form related) and the general control factors. This comparison will allow us to evaluate our data in terms of the content-form debate: in essence, the model including content and cognitive factors represents the content position of the argument, while the conservative model represents the form position. Although it is possible to estimate the contribution of content on presence without this comparison (by examining the partial correlations, for example), making this comparison allows one to link the data to the theoretical debate far more strongly. Statistically, such a comparison is simple – one can perform a significance test on the difference between the error variances of two models [26], which in effect compares the models in terms of their R^2 values.

Although the idea of such a model comparison sounds straightforward in principle, it is far from simple to find a set of form related factors which satisfactorily expresses a consensus of published research. The list of factors we used was derived from the compilation used in [12] but was expanded slightly. These are immersion related factors such as display size and passive haptics used, and attention management strategies (keeping the room dark, preventing interruptions during the experience, etc.). The general control factors include age, amount of time since the subject last played a flight simulation, and their enjoyment of flight simulations (these factors are defined and justified in the measures section in 2.3 above). By comparing the fit of these two models, it should be possible to gain an insight into the relative contributions of content and cognitive factors to particular aspects of the presence experience.

3. Results

The data were analyzed using a set of four multiple regression analyses, one for each of the four ITC-SOPI factors. In each case, the ten predictors listed in table 1 were used. In order to more clearly show the contribution of the content and cognitive factors to the variance of the ITC-SOPI factors, we tested the difference in model fit between the full ten factor model and the reduced four factor conservative model. As discussed in 1 and 2.4 above, this conservative model poses *presence management* as the major predictor (it includes measures of well investigated variables in presence such as display size [27], passive haptics [22], and focusing of attention on the VE [12]). The conservative model also includes *age*, *enjoyment*, and *experience-measure delay* factors as general controls.

3.1 Spatial factor

For this factor, the ten predictor model is significant ($F = 17.41$, $p < 0.00001$) and gives $R^2 = 0.28$. The significant predictors (at the 0.01 level) are *thematic inertia*, *evaluation of realism*, *content knowledge* (as a negative factor), *presence management* and *age* (see table 2 below for corresponding partial correlations). The difference between the fit of this model and that of the reduced conservative model (which has $R^2 = 0.15$) is significant ($F = 12.67$, $p < 0.00001$) – see table 6.

Factor	Partial correlation
Thematic inertia	0.28
Evaluation of realism	0.18
Content knowledge	-0.12
Presence management	0.19
Age	0.14

TABLE 2: Significant predictors for the* spatial *factor, with partial correlations.

3.2 Engagement factor

Again, the ten predictor model is significant ($F = 30.77$, $p < 0.00001$) with $R^2 = 0.40$. The significant predictors (at the 0.01 level – see table 3 below) were the same as for spatial presence. These were: *thematic inertia*, *evaluation of realism*, *content knowledge* (as a negative factor) *presence management* and *age* (see table 3). The difference in fit between this model and the conservative one (whose $R^2 = 0.26$) is again significant ($F = 17.86$, $p < 0.00001$).

Factor	Partial correlation
Thematic inertia	0.33
Evaluation of realism	0.13
Content knowledge	-0.14
Presence management	0.33
Age	0.20

TABLE 3: Significant predictors for the engagement factor, with partial correlations.

3.2 Naturalness factor

Although the ten predictor model for this factor is significant ($F = 18.14$, $p < 0.00001$) and the fit is good ($R^2 = 0.29$), the significant predictors differ from the two previous models. As before, *thematic inertia*, *evaluation of realism*, *presence management* and *age* are significant predictors; however, *content knowledge* makes no contribution, and *priming* is a significant predictor (see table 4).

Factor	Partial correlation
Thematic inertia	0.24
Evaluation of realism	0.25
Presence management	0.16
Priming	0.10
Age	0.19

TABLE 4: Significant predictors for the naturalness factor, with partial correlations.

As with the other models, the difference in fit between this and the conservative model (with $R^2 = 0.13$) is significant ($F = 13.65$, $p < 0.00001$) – see table 6.

3.3 Negative effects factor

The ten predictor model is again significant ($F = 3.57$, $p < 0.00026$), as one would expect with such a large sample size; however, it shows very weak fit ($R^2 = 0.07$). The pattern of predictors is also quite different – only *thematic inertia* and *presence management* are significant predictors (see table 5). Again, this model explains more variance than the conservative model, which itself has a very weak fit ($R^2 = 0.04$), but the effect size of the difference is noticeably smaller – indeed, it does not reach significance at the 0.01 level ($F = 2.60$, $p < 0.02$) – see table 6.

Factor	Partial correlation
Thematic inertia	0.15
Presence management	0.13

TABLE 5: Significant predictors for the negative effects factor, with partial correlations.

3.4 Overall comparison of model fit

Table 6 below summarizes the differences in model fit (R^2) between the ten predictor model and the conservative model.

ITC-SOPI Factor	R^2 for ten predictor model	R^2 for conservative model
Spatial	0.28	0.15*
Engagement	0.40	0.26*
Naturalness	0.29	0.13*
Negative effects	0.07	0.04

TABLE 6: Summary of model fits for the ten predictor and conservative models (asterisk indicates p < 0.01 for the difference in fit between the models)

For all four ITC-SOPI factors, the difference between model fit is significant at the 0.05 level. At the 0.01 level however, the models for the negative effects factor do not show a significant difference in fit. In general, the ten predictor model explains substantially more presence variance than the conservative model.

4. Discussion

For the remainder of this paper, we will consider firstly some caveats and limitations of our design and sample, followed by a discussion of the theoretical importance of the significance and lack of significance of the ten predictors. We will end the paper considering the overall importance of content and cognitive factors in understanding presence. For the purposes of comparison during our discussion, table 7 below provides a summary of the analysis of the ten predictor model presented in section 2.4 above, showing the partial correlations of the significant predictors for each of the ITC-SOPI factors, as well as the model fit.

4.1 Implications of the design and sample

Possible effects of experience-measurement delay

In order to capture this large number of subjects, the design required violating the requirement that the ITC-SOPI be administered immediately after the experience. Although there exists no theoretical explanation as to why an experience-measurement delay should introduce systematic error into the presence measure (or indeed, a prediction of what such an effect would be), we controlled for this by asking for an estimate of the delay. Our analysis revealed no delay effects in any of the ITC-SOPI factors. One may conclude that with a quantification granularity of one day, no experience-measure delay effects are apparent. Although it is possible that an effect exists over a period less than one day, it would have to be a non-linear effect acting over a period of less than one day, and with no further effect after one day.

Positive bias due to enjoyment

As a large number of the participants in this study were likely to be habitual simulation users, it was necessary to control for a possible positive bias in their responses. This was achieved by use of the enjoyment predictor. The reported degree of enjoyment was, as expected, high – a mean score of 29.7 (on a scale ranging from 6 to 42), but it was not significantly skewed. However, it is important to note that enjoyment was not a significant predictor of any of the four ITC-SOPI factors. It is therefore possible to state in subsequent conclusions that the reports of presence given by our sample were not unduly inflated by their enthusiasm for the content.

Factor	Spatial Presence	Engage-ment	Natural-ness	Negative effects
Thematic Inertia	0.28	0.33	0.24	0.15
Evaluation of realism	0.18	0.13	0.25	-
Content knowledge	-0.12	-0.14	-	-
Presence management	0.19	0.33	0.16	0.13
Priming	-	-	0.10	-
Age	0.14	0.20	0.19	-
Overall R^2	0.28	0.40	0.29	0.07

TABLE 7: Comparison of partial correlations and model fit for the significant predictors of the ten predictor model on the 4 ITC-SOPI factors (a hyphen indicates the predictor was not significant at the 0.01 level)

Gender and age of participants

Central to any modeling study is a large sample which is able to represent its population correctly [28]. In terms of age, this is an extremely good sample. In fact, it provides a wider age range than any comparable presence study we have been able to find (compare for instance, with [12], [25] or [29]).

Although this study used a large, self selected sample, it contains no women respondents, which is a concern. The choice of population (flight simulation users) was made as it presents a population of habitual VE users who have knowledge at several levels of relevance of the content of the VE. It is unfortunate that a population which is so useful for our purpose should also have a massively imbalanced gender distribution. From a cognitive perspective, one of the most serious concerns is that of possible gender differences in spatial abilities, which would have a great impact on presence [7]. Currently, there is no definitive answer to whether such a gender difference exists; Some time ago evidence for a difference was clear, but thought to be diminishing over time [30]. Later meta-analyses revealed a more confused, inconclusive picture [31] [32]. It is therefore possible that some of the findings of this study may not generalize across the genders. However, many of the theoretically important findings of this paper (such as the contributions of content knowledge), probably rely more on semantic processes than spatial ones, so even if such differences exist, they may not negate the described effects.

Degree of control over display variables

A key feature of this design is the controlling of system variables to examine the role of content variables. This was achieved in by measuring presence management practices (which includes subjects' control over display and interface variables), as well as sampling only those who use a single software platform. It should be noted that although the software package was kept constant, it is still possible to have slight variations in terms of content as well as display. The software we selected (as with all desktop based simulations) allows users to trade display fidelity for simulation update rate, through adjusting a number of simulation and display parameters within a narrow range. Therefore, the exact degree of visual fidelity which any particular subject experienced during their last simulator session is not known. However, the range of such modifications allowed by the software is limited, so it is possible to understand this control as limiting such effects. Also, it is important to recognize that although this can be correctly understood as a threat to the internal validity of this design, our choice of a large sample of simulation users reporting on their experiences with their usual gaming situation gives this study an enviable degree of external validity; in an important sense, this is an example of the trading off of internal validity for external validity which is unavoidable in this type of work [28].

4.2 Thematic inertia and priming

Most interesting of the results obtained is perhaps the role of thematic inertia. It is a significant predictor of all four ITC-SOPI factors, and in all cases its contribution to the ITC-SOPI factor is either higher or only slightly less than that of *presence management*. We constructed the measure of presence management to include measures of display size and passive haptics, which have been established as important factors in presence [20, 22, 27]; however, the current data suggest that, if one holds the software platform relatively constant, then this cognitive factor is on average at least as important as display and attention related factors. One possible explanation for this phenomenon is that those with high thematic inertia gain more benefit from better displays, and thus have learned presence management strategies. However, this is unlikely, as the overall correlation between presence management and thematic inertia, although significant, is low (r = 0.31); also, if this were the case, we would not expect to see both of these factors appear as significant predictors in the multiple regression, due to a high degree of shared variance. A more theoretically driven explanation which is consistent with this data is that while presence management can be learnt, thematic inertia is probably part of a cognitive style and therefore cannot be learnt [12]. As discussed in section 1 above, thematic inertia likely contributes to presence through enabling the spreading of semantic activation; it is therefore probably relatively independent of perceptual factors (associated with the processing of the display). Subjects who are fortunate enough to have high thematic inertia and engage in presence management strategies would undoubtedly have the highest presence scores.

Intriguing is the lack of effect of priming on presence, given that priming has been found to be effective when manipulated experimentally [11]. It only seems to affect the *naturalness* factor, and then only to a slight degree (a partial correlation of 0.1). One possible explanation is that priming is effective, but subjects do not make use of it; however, this is at odds with the evolution of presence maximization strategies argument [12], which proposes that game players will evolve behaviors which maximize their presence experiences. Closer examination of the data reveals that if one re-computes the regressions after removing thematic inertia as a predictor, then priming becomes a significant predictor of all ITC-SOPI factors except negative effects. This suggests that priming has a higher covariance with thematic inertia than with the ITC-SOPI factors. It is probably correct to say that thematic inertia and priming both measure some more general cognitive factor. It seems reasonable to suggest that thematic inertia measures an automatic quality of cognition, where exposure to one type of stimuli associated with a content area (a book) automatically activates cognitions about related stimuli (a simulation) probably by means of the spreading of semantic activation. On the other hand, priming measures *active* engagement in behaviors. It seems reasonable that without the tendency measured by thematic inertia, priming would not be effective. Thus, subjects without the tendency would not have evolved priming behaviour. Also, not all those who have a high degree of thematic inertia would necessarily engage in priming behaviors for any number of practical reasons (limited time, lack of priming materials, etc.); priming would therefore have a much higher degree of error variance than thematic inertia. We can therefore expect thematic inertia to be a better predictor of presence than priming is.

4.3 The role of content knowledge and evaluations of realism

This study used measures of three types of content knowledge: Specific knowledge about the simulated content (*content knowledge* factor), general knowledge about the content (*hobby cluster* factor), and content irrelevant knowledge (*simulator mechanics knowledge* factor). For the spatial and engagement ITC-SOPI factors, specific knowledge of the VE content reduces the presence experience. The effect on the spatial factor can be understood in terms of the expectations for the system held by the user [16], as discussed in section 1 above. Therefore, the more specific content knowledge the user has, the more detailed and specific the expectation will be. Given that the simulation is giving a set degree of fidelity, users with more specific knowledge should notice more mismatches between their expectations and the display, leading to a reduction in presence. With relevant but non-specific knowledge of the simulated content, one would expect this effect to be significantly reduced, as generalized knowledge would not lead to specific expectations; and the data suggest that it has no effect at all. In the case of the engagement factor, we would suggest that subjects would be more engaged with a system that does not violate their expectations, by two mechanisms: firstly, their attention would not be diverted to the errors or omissions in the simulated content, and secondly, they would experience more interest, fun, and have their attention more focused on systems which present the content which they expect. Content irrelevant knowledge leads to no expectation of the interaction with the system, and it therefore produces no effect on presence on either the spatial or engagement factors.

In the case of the naturalness and negative effects factors, there are no content knowledge effects at all. It is simple to understand why the negative effects factors should not be affected by content knowledge, because simulator sickness is well understood to be due to a mismatch in information between the visual and vestibular systems [33], and therefore higher level cognition is unlikely to have an impact. However, how natural a VR system is experienced as, should be affected by one's expectations of the content being modeled, as is the case with the spatial and engagement factors. One might argue that although this is the case, the ITC-SOPI items of this factor are at an extremely non-specific level of interpretation (for example, "the content seemed believable to me"). It is possible that for the given population (flight simulation hobbyists), the lack of effect is due to a floor effect – they all have enough knowledge about aviation that the responses to such items would vary very little. This however is not borne out by the data – the naturalness factor has a mean and variance comparable to the other ITC-SOPI factors. Another possible explanation for this phenomenon is that the expectations associated with the naturalness factor are implicit rather than semantic – that is, they are expectations about how the simulation behaves and responds to input, rather than being explicit expectations about the shape or layout of the physical space and its meaning. Although we do not have any means of supporting this hypothesis with the current data, it is supported, we believe, by the theoretical distinction drawn between implicit and explicit cognition, which is for instance used in implicit memory research (such as [34]) and the mental models literature (for example, [35]).

A final interesting effect which appears in this data (or rather, fails to appear) is with regard to content irrelevant knowledge (the *simulator mechanics* *knowledge* factor). Even though we used a large sample, which would typically give significant results even for small effects, no effects were found. One can conclude that irrelevant information neither contributes nor interferes with presence. This, together with the contribution of relevant information presented above, suggests that the presence experience is constructed from selected subsets of perceptual and conceptual information as suggested in [10] (and to a lesser extent in [14]). It also supports the notion that attention and cognitive resources are allocated in terms of that construction, effectively expressing a bias for content relevant information, while excluding irrelevant information [10]. This suggests that presence is not due to a 'willing suspension of disbelief" (discussed in [36] and [37]), but rather that information which might lead to disbelief is filtered out, so that the only aspect of willingness in the presence experience may the decision to engage with the VR system. If this is true, then the research question becomes: under which conditions does such a filtering process engage, and how can one control the coarseness of the filter?

The question of the contribution of display realism and simulation fidelity to presence has been dealt with in the literature to a largely satisfactory degree [3] [38] [39]. We were interested in the *perception of realism* held by the users of simulations. As argued in [40], the fidelity or realism of a scene could be measured completely objectively by describing the various display parameters, and for content, one could measure fidelity in terms of variations between the simulated model and the actual phenomena being simulated. However, whether a subject finds a simulation realistic is a different matter; it returns to expectations about the content. Asking a subject to provide an assessment of the realism of a simulation is a measure of a very general, high level expectation of the experience the simulation will deliver. In this study, given that the simulation platform was kept relatively constant across all participants, any differences in their perceptions of realism can be more readily attributed to cognitive factors than to display factors; also the items in this factor asked subjects not about the perceived realism of the last simulator session (which would have been an actual measurement of the system), but of simulation software *in general*. We can assume that such an average evaluation of realism would have existed before the subjects played their last simulator session; and therefore it would have acted as an expectation for that session. As this expectation is extremely generalized, it is should be simple to satisfy even with a desktop simulation. This is borne out by the data – the evaluation of realism is a positive predictor (with high partial correlations) of all factors of the ITC-SOPI except negative effects.

4.4 The interaction of expectations and mediated content in presence

As discussed in 4.3 above, a high evaluation of realism was associated with an increase in presence, due to the generalized nature of the expectation associated with realism evaluations. Conversely, for content knowledge, a negative relationship existed with presence, due to the highly specific expectations associated with a large degree of content knowledge. At the same time, knowledge not associated with the simulation content (such as knowledge of the simulation mechanics), had no effect, as it creates no expectation for that particular content. During the mediated experience, the simulation provides a number of perceptual cues on several modalities. If these cues are interpreted as matching the expectations arising from the content knowledge, then the subject will have a coherent presence experience in the system; if not, the lack of match will lead to a reduced presence experience through the attracting of attention to perceived errors in the content, as well as a reduced sense of naturalness and reduced engagement with the material [10]. Such a mismatch is more likely to occur in the face of highly specific expectations, and less likely in the face of generalized expectations. We can summarize this discussion in a general principle: VE relevant knowledge creates a cognitive context in terms of expectations, with more knowledge leading to more specific expectations; and presence is more likely to occur when expectations are matched by the VE system.

This content expectation principle can be seen in the partial correlations of the content relevant factors – evaluation of realism, hobby clustering and content knowledge. If one orders them with respect to how specific an expectation we predict from each one, and plots them against their partial correlations (see figure 1), then the predicted pattern is discernible for all the ITC-SOPI factors except negative effects.

It should be noted that hobby clustering did not give a significant partial correlation with any of the ITC-SOPI factors; this means, in the strictest sense, that the population value of the partial correlation is zero. With regard to the hypothesis of generality of expectation, we can interpret this to mean that at the level of generality found at the hobby cluster level of knowledge, the contribution to presence is negligible; the size of its effect is so small as to be undetectable with our sample.

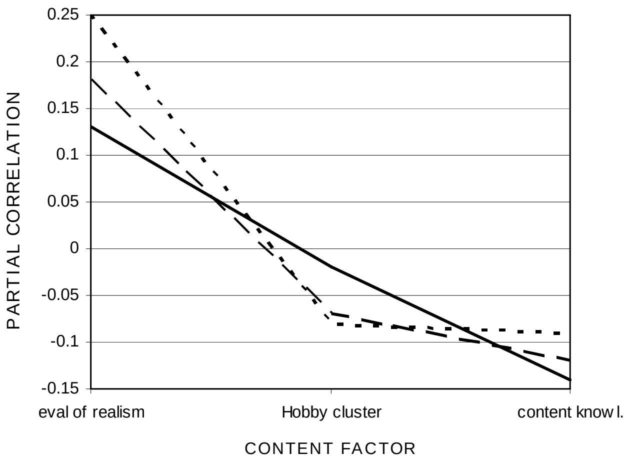

FIGURE 1: Plot of partial correlations of content factors, in decreasing level of generality of expectation (from left to right). The partial correlations with three ITC-SOPI factors are shown - *Spatial* is the dashed line; *Engagement* is the solid line; *Naturalness* is the dotted line.

We would like to suggest that its strength of effect represents a half-way point between the effects of content knowledge and evaluation of realism; we believe our expectations hypothesis is theoretically strong enough to support this idea. However, more data is required to categorically make this statement. A future study could overcome this weakness by refining the measure of generality of expectation so as to produce a continuous model of this effect.

4.5 Relative contribution of content and cognitive factors to presence

In general terms, the models we computed show that the addition of the content and cognitive factors add significant fit over the conservative model, for all ITC-SOPI factors except *negative effects* (summary in table 6 above). The conservative model replicates the large body of published work which argues for the importance of display related factors in presence (such as [22], [40, 2], [41], [42] and others); this validates the general procedure used in this study. However, the difference in fit between the models highlights the importance of considering content related factors when predicting presence. Although we have only included a limited set of display related factors in our *presence management* factor (as any study must), it is highly unlikely that the amount of increase in model fit brought about by adding the content related factors is simply an artifact of our selection of display factors, or of the method used. Furthermore, our use of the ITC-SOPI measure allows us to separate out the effect of these factors on several components of the presence experience. Therefore, if one argues that content factors are an important contributor to engagement but not spatial presence (as is done, for example, in [2]), our models would reply that this is incorrect. We can provide evidence that content factors affect both spatial presence, and the other factors – although it should be noted that it is still unknown if there is a causal flow between the ITC-SOPI factors, so that engagement might cause spatial presence, for example, or vice versa.

5. Conclusion

We have argued that these findings strongly support the idea that parallel to considering the role of the display and immersion in presence (form), it is beneficial to consider the role of VE content. To understand the interaction of content and form factors, it is important to consider the cognitive context in which the form in processed (both in terms of short term effects such as priming, and long term structures such as those measured by thematic inertia).

It should be noted that even our most powerful model (the ten factor model predicting engagement) explained less than half the variance in presence scores; a great deal of work clearly remains to identify further content, display and possibly other classes of variables which are important factors in the presence experience.

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References

[1] M. J. Schuemie, P. van der Straaten, M. Krijn and C. A. P. G. van der Mast, *Research on presence in virtual reality: A survey.*, Cyberpsychology & Behaviour, 4 (2001), pp. 182-210.

[2] M. Slater, *A note on presence terminology.*, Presence Connect, 3 (2003).

[3] J. Lessiter, J. Freeman, E. Keogh and J. Davidoff, *A cross-media presence questionnaire: The ITC-Sense of Presence Inventory*, Presence: Teleoperators and Virtual Environments., 10 (2001), pp. 282-297.

[4] H. M. McLuhan, *Understanding media: The extensions of man*, McGraw Hill, New York, NY, 1964.

[5] S. L. Calvert, *The social impact of virtual reality*, in K. Stanney, ed., *Handbook of Virtual Environment Technology*, Erlbaum, Hillsdale, NJ, 2001.

[6] D. Nunez and E. H. Blake, *Cognitive presence as a unified concept of virtual reality effectiveness*, *1st International Conference on Computer Graphics, Virtual Reality, Visualization and Interaction in Africa (AFRIGRAPH 2001)*, ACM Press, Cape Town, South Africa, 2001, pp. 115-118.

[7] W. Wirth, T. Hartmann, S. Böcking, P. Vorderer, C. Klimmt, H. Schramm, T. Saari, J. Laarni, N. Ravaja, F. R. Gouveia, F. Biocca, A. Sacau, L. Jäncke, T. Baumgartner and P. Jäncke, *A Process Model of the Formation of Spatial Presence Experiences*, 2004.

[8] C. Fencott, *Presence and the Content of Virtual Environments*, *2nd International Workshop on Presence*, Essex, U.K., 1999.

[9] T. W. Schubert, F. Friedmann and H. T. Regenbrecht, *The experience of presence: Factor analytic insights.*, Presence: Teleoperators and Virtual Environments., 10 (2001), pp. 266-281.

[10] D. Nunez, *A constructionist cognitive model of presence.*, *7th International workshop on presence. (PRESENCE 2004)*, Valencia, Spain, 2004, pp. 313-316.

[11] D. Nunez and E. H. Blake, *Conceptual priming as a determinant of presence in virtual environments.*, *2nd International Conference on Computer Graphics, Virtual Reality, Visualisation and Interaction in Africa (AFRIGRAPH 2003)*, Cape Town, South Africa, 2003, pp. 101-108.

[12] D. Nunez and E. H. Blake, *Learning, experience and cognitive factors in the presence experiences of gamers: An exploratory relational study.*, Presence: Teleoperators and Virtual Environments (In press).

[13] D. E. Rumelhart and A. Ortony, *The representation of knowledge in memory.*, in R. C. Anderson, R. J. Spiro and W. E. Montage, eds., *Schooling and the Acquisition of Knowledge*, Lawrence Erlbaum Associates, 1977.

[14] W. Wirth, P. Vorderer, T. Hartmann, C. Klimmt, H. Schramm and S. Böcking, *Constructing presence: Towards a two-level model of the formation of spatial presence experiences*, *6th Annual International Workshop on Presence*, Aalborg, Denmark, 2003.

[15] C. Martindale, *Cognitive Psychology: A Neural Network Approach*, Brooks/Cole, 1990.

[16] D. Nunez, *How is presence in non-immersive, non-realistic worlds possible? ACM AFRIGRAPH 2004*, Stellenbosch, South Africa, 2004, pp. 83-86.

[17] M. Mori, *Bukimi no tani (The uncanny valley)*, Energy, 7 (1970), pp. 33-35.

[18] avsim.com, *The AVSIM 2003 survey*, (2003).

[19] C. Youngblut, *Experience of presence in virtual environments*, Institute for defense analyses, 2003.

[20] W. A. IJsselsteijn, H. De Ridder, J. Freeman and S. E. Avons, *Presence: Concept, determinants and measurement.*, *Proceedings of the SPIE*, 2000, pp. 520-529.

[21] D. Nunez and E. H. Blake, *The thematic baseline technique as a means of improving the sensitivity of presence self-report scales.*, *6th International Workshop on Presence*, Aalborg, Denmark, 2003.

[22] B. Insko, *Passive haptics significantly enhances virtual environments*, *Department of Computer Science*, University of North Carolina at Chapel Hill, 2001.

[23] S. Nichols, C. Haldane and J. R. Wilson, *Measurement of presence and its consequences in virtual environments.*, International Journal of Human Computer Studies, 52 (2000), pp. 471-491.

[24] K. E. Bystrom and W. Barfield, *Effects of participant movement affordance on presence and performance in virtual environments*, Virtual Reality: The Journal of the Virtual Reality Society, 2 (1996), pp. 206-216.

[25] W. Barfield and S. Weghorst, *The sense of presence within virtual environments: A conceptual framework.*, in G. Salvendy and M. Smith, eds., *Human-Computer Interaction: Software and Hardware Interfaces*, Elsevier, 1993, pp. 699-704.

[26] J. Neter, W. Wasserman and G. A. Whitmore, *Applied statistics*, Allyn and Bacon, Boston, MA., 1988.

[27] C. Hendrix and W. Barfield, *Presence within virtual environments as a function of visual display parameters*, Presence: Teleoperators and Virtual Environments, 5 (1996), pp. 274-289.

[28] R. Rosenthal and R. L. Rosnow, *Essentials of behaviour research: Methods and data analysis.*, McGraw Hill, New York, NY, 1991.

[29] C. Youngblut and B. T. Perrin, *Investigating the relationship between presence and task performance in virtual environments.*, *IMAGE 2002 Conference*, Scottsdale, AZ., 2002.

[30] H. Stumpf and E. Klieme, *Sex-related differences in spatial ability: more evidence for convergence.*, Perceptual and Motor Skills, 69 (1989), pp. 915-921.

[31] D. Voyer, S. Voyer and M. P. Bryden, *Magnitude of sex differences in spatial abilities: a meta-analysis and consideration of critical variables.*, Psychological Bulletin, 117 (1995), pp. 250-270.

[32] E. Coluccia and G. Louse, *Gender differences in spatial orientation: A review*, Journal of Environmental Psychology, 24 (2004), pp. 329-340.

[33] R. S. Kennedy, L. J. Hettinger and M. G. Lilienthal, *Simulator Sickness*, in G. H. Crampton, ed., *Motion and Space Sickness*, CRC Press, Boca Raton, FL, 1988.

[34] P. Graf and L. Ryan, *Transfer-appropriate processing for implicit and explicit memory.*, Journal of Experimental Psychology: Learning, Memory, and Cognition, 16 (1990), pp. 978-992.

[35] P. N. Johnson-Laird, *Mental Models: Towards a Cognitive Science of Language, Inference, and Consciousness.*, Harvard University Press, Cambridge, MA., 1983.

[36] M. L. Ryan, *Cyberspace, Virtuality, and the Text. In Cyberspace Textuality: Computer Technology and Literary Theory*, Indiana University Press, Bloomington, ID., 1999.

[37] C. Botella, R. M. Baños and M. Alcañiz, *A psychological approach to presence*, *6th International Workshop on Presence*, Aalborg, Denmark, 2003.

[38] M. Slater and A. Steed, *A virtual presence counter*, Presence: Teleoperators and Virtual Environments., 9 (2000), pp. 413-434.

[39] M. Meehan, B. Insko, M. Whitton and F. P. Brooks, *Physiological measures of presence in stressful virtual environments.*, *SIGGRAPH 2002*, San Antonio, USA, 2002, pp. 645-652.

[40] M. Slater and S. Wilbur, *A framework for immersive virtual environments (FIVE): Speculations on the role of presence in virtual environments.*, Presence: Teleoperators and Virtual Environments., 6 (1997), pp. 603-616.

[41] C. Sas and G. M. P. O'Hare, *The presence equation: An investigation into cognitive factors which underlie presence within non-immersive virtual environments.*, *The 4th Annual International Workshop on Presence*, Philadelphia, PA, 2001.

[42] W. Barfield and C. Hendrix, *The effect of update rate on the sense of presence within virtual environments.*, Virtual Reality: The Journal of the Virtual Reality Society, 1 (1995), pp. 3-16.