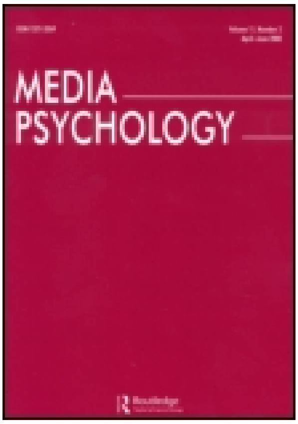

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User Experience in 3D Stereoscopic Games

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User Experience in 3D Stereoscopic Games

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New display technologies, such as 3D stereoscopic displays, provide opportunities to enhance the user experience (UX) in digital games. A widely-held belief is "the more stereo, the better experience." The purpose of this study is to examine this belief and evaluate the added value of 3D stereo to the UX in games. Stereo separation in a display was varied, and a multidimensional UX was measured using a psychological Presence-Involvement-Flow Framework^2 *(PIFF*^{2}*) in a between-subjects design. The PIFF*^{2} *findings were further supported by both qualitative and objective measures. Users' descriptions of the game were included as well as adverse symptoms, open-ended negative aspects of 3D stereo, basic eye physiology, objective performance metrics, and fundamental background variables. This hybrid qualitative-quantitative methodology shows that more stereo does not lead to better UX. It was shown that a moderate level of stereo separation affected the UX most by increasing the sense of presence among the users. These results deepen the previous findings in investigating the stereo effect in different media. The advantage of using multidimensional measures to evaluate UX, the added value of 3D stereo, and the practical implications of the results are further discussed.*

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Over the last 10 years, the popularity of entertainment digital games, that is, PC and console games, has increased significantly to the point that these games have become the fastest-growing field in the entertainment industry (Entertainment Software Association [ESA], 2009). This development is apparent in various areas: The entertainment software industry is a major employer in the field of software programming and continues to grow as a source of employment. In the United States, digital games are played in 68% of households. Digital games clearly have a new role in our society; they are no longer entertainment for marginal users. For many of us, games have become a way of life. This development can be seen in studies investigating the similarities in economic structures between online games and the real world (Giles, 2007). As players generate intense relationships with digital games, psychology plays a central role in developing the game–gamer relationship. Central to this relationship is the experience games provide (Hunicke, LeBlanc, & Zubek, 2004; Johnson & Wiles, 2003; Lazzaro & Keeker, 2004). Consequently, investigation of the user experience (UX) in games has become a lively research area (Bernhaupt, Eckschlager, & Tscheligi, 2007; Ijsselsteijn, de Kort, Poels, Jurgelionis, & Bellotti, 2007; Takatalo, Häkkinen, Kaistinen, & Nyman, 2007). The multifaceted concept of the UX is here understood as the gamers' perceptions and responses that result from playing a game (International Standardization Organization [ISO], 2008). We regard these perceptions and responses as being essentially subjective and psychological in nature.

Experientially, one of the most influential game characteristics is the capability of games to provide visually realistic and life-like 3D environments for the game-play action (Rosenbloom, 2003; Wood, Griffiths, Chappell, & Davies, 2004). With third-generation consoles, which can show high definition images (Andrews & Baker, 2006), the question of increased realism in the UX has become important (Serviss, 2005). Stereoscopic display technologies (Dodgson, 2005; Gostrenko, 2008; Häkkinen, Liinasuo, Takatalo, & Nyman, 2005; Kawai, Shibata, Shimizu, Kawata, & Suto, 2004; Surman, Hopf, Sexton, Lee, & Bates, 2006; Zhang & Travis, 2006) pose more challenges than ever for UX research in games because these technologies increase the realism of the games even further. Research in the field should be able to determine, whether stereoscopic images provide added value from the UX point of view and, if so, then what the properties of this enhanced experience are.

The focus of this study is to analyze how increasing the stereo separation affects the UX in a game. Few studies have attempted to analyze how stereo affects the media experience. The current study contributes to the available findings with a questionnaire-based tool specifically designed for assessing the multidimensional UX in games. In addition, other methods, such as open-ended qualitative measures, eye physiology, and performance metrics, are used to support the findings. This quantitative-qualitative approach enables us to determine the key parameters of the subjective UX in 3D stereo games. Understanding how changing the display parameters, such as the level of stereo separation, affects the UX has potential to increase our understanding of how to create a better UX in games and media in general.

UX IN STEREOSCOPIC DISPLAYS

Most of the user studies of stereoscopic displays focus on negative experiences, that is, on eye strain and sickness symptoms. The focus on the adverse symptoms is warranted, because the stereoscopic displays induce convergence-accommodation conflict in which the natural relationship between the convergence and the accommodation systems is disrupted (Hiruma, Hashimoto, & Takeda, 1996; Oohira & Ochiai, 1996). However, there are also studies that focus on the positive aspects of the stereoscopic effect. In virtual environments, stereo has been found to enhance depth perception and eye-hand coordination (McMahan, Gorton, Gresock, McConnell, & Bowman, 2006; Treadgold, Novins, Wyvill, & Niven, 2001), for example. In addition to performance measures, positive experiences are related to stereo effect.

Ijsselsteijn, de Ridder, Freeman, Avons, and Bowhuis (2001) used a within-subject design to study both positive and negative aspects in stereoscopic, nonstereoscopic, still, and moving video conditions. A 100-second rally video was shown in a 50-degree horizontal field-of-view projection display, and four visual analog rating scales were used to analyze the sense of presence (e.g., "To what extent did you feel present in the displayed sequence—as if you were really there'?"), involvement "How involved were you in the displayed sequence?," illusory perception of self-motion, that is, vection "To what extent did you feel that you were moving along the track, as though you were traveling with the car?," and sickness symptoms "To what extent did watching the sequence make you feel sick?" The results showed that both image motion and stereoscopic presentation increased the subjectively evaluated presence. Furthermore, it was shown that the presence ratings were more affected by image motion than by the stereoscopic effect. Motion also increased the evaluations of vection and involvement.

Rajae-Joordens, Langendijk, Wilinski, and Heynderickx (2005) reported similar findings in their within-subject study in which 20 experienced gamers played a first-person shooter (FPS) game called *Quake III* for two consecutive 45-minute periods. One of these periods was played with a 20-inch 2D display, and the other was played with the same display in 3D stereoscopic mode. The participants filled in a presence questionnaire (e.g., "I had a sense of being in the game scenes") and an engagement questionnaire (e.g., "I would have liked this game to continue," "I enjoyed myself") as well as several sickness questionnaires. In addition to subjective methods, the authors measured participants' galvanic skin response (GSR) and heart rate (HR). The results showed that both subjectively evaluated presence and engagement were higher in the 3D stereo condition. No sickness or eye strain symptoms were found. The GSR recordings were consistently higher in the 3D condition as compared to the 2D condition. No differences were found in participants' HR measures between the displays. The authors concluded that 3D elicited more emotions, intense, realistic experiences, and a stronger as well as a sustainable feeling of presence. GSR and other measures of electrodermal activity (EDA) are considered indicators of emotional arousal (Lang, 1995), that is, the degree of activation in an organism, which can be described with a continuum from deep sleep to high excitement (Visualthesaurus, 2010). The role of HR in understanding the UX is more ambiguous; some studies have related HR to presence in virtual environments (Meehan, Insko, Whitton, & Brooks, 2002), for example, whereas other studies have not found any such connection (Wiederhold et al., 2003).

Both Ijsselsteijn, de Ridder, et al.'s (2001) and Rajae-Joordens et al.'s (2005) findings are in line with previous studies indicating that the sense of presence (Lombard & Ditton, 1997) seems to be sensitive to various display parameters. In addition to stereo, the size of the display (Ijsselsteijn, de Ridder, et al., 2001; Lombard, Reich, Grabe, Bracken, & Ditton, 2000), a high-definition image quality (Bracken, 2005), and the type of the display (CRT vs. HMD; Takatalo, Häkkinen, Komulainen, Särkelä, & Nyman, 2006) were shown to increase the experienced presence. The above findings show a close relationship between physical presence and user interface, that is, how the media looks. However, physical presence is only a part of the concept of presence, presence is only a part of UX and an interface is only a part of a digital game.

Presence literature conceptualizes presence as a multi-dimensional construct with numerous interrelated but distinct subcomponents (International Society for Presence Research, 2010). For example, in digital games five subcomponents related to both physical and social presence have been found (Takatalo, Häkkinen, Särkelä, Komulainen, & Nyman, 2006). Today, it is widely accepted that the concept of presence constitutes only a part of multidimensional UX (Bernhaupt, 2010; Bernhaupt et al., 2007; Ijsselsteijn, de Kort, et al., 2007; Takatalo et al., 2007). In order to understand UX, other game components besides the interface, such as the narrative (e.g., story) and the mechanics (e.g., goals, rules; Hunicke et al., 2004) need to be considered. This requires additional measures, which are presented in both theoretical and empirical models of UX in games. Our concentration is on the empirical findings in the field and on providing a state-of-the art tool in order to analyze systematically the effects of the 3D stereo display on the UX.

UX IN GAMES

Numerous concepts have been used to describe the subjective perceptions and responses resulting from playing a digital game (ISO, 2008). For example, immersion, fun, presence, involvement, engagement, and flow, have been related to the UX in games (Brown & Cairns, 2004; Ijsselsteijn, de Kort, et al., 2007; McMahan, 2003; Nakatsu, Rauterberg, & Vorderer, 2005; Sweetser & Wyeth, 2005). Often these concepts are defined quite broadly; for instance, presence is "the sense of being there," while flow is "an optimal experience." Various psychological faculties are attached to these concepts; for example, concentration, emotions, and cognitive evaluations of a game's challenges are each referred to as immersion (McMahan, 2003). Thus, there is a good deal of overlap among these concepts, and consequently, the challenges to understanding and measuring them are accumulating. In most cases the concept itself (e.g., flow) cannot be reached and measured in a straightforward manner. Instead, the subcomponents must be recognized and measured.

An overview of the ten general UX subcomponents found in nine empirical studies is shown in Table 1. The sample sizes in these studies vary from a few dozen to thousands, and the number of studied subcomponents varies from three to ten. There is conceptual overlap among the subcomponents, depending on both the scope and the methodology of the approach. However, the majority of the studies have some kind of reference, both to the emotions and to cognitively evaluated challenges, which both are relevant subcomponents of flow (Csikszentmihalyi, 1975). Some studies have acknowledged presence as a potential subcomponent of the UX. Presence is often understood as *sensory immersion*, which taps the perceived realness and the attention aspects of the suggested "Big-Three" presence construct (the sense of space-realness-attention; Laarni, 2003). Since the stereo effect in games has been studied by means of psychophysiological methods (Rajae-Joordens et al., 2005), we present some psychophysiological findings concerning the study of multidimensional UX in games.

PSYCHOPHYSIOLOGICAL METHODS

Psychophysiological methods provide temporally accurate and objective information about the human physiology. Physiology underlies human experience, but in order to understand what kind of experience it indicates, other—often subjective—information is associated with the objective information (Rajae-Joordens et al., 2005; Ravaja, 2004). Let's take the case of a heightened EDA in FPS's for example. In one case (*Quake III*) heightened EDA in the 3D stereo condition was interpreted as an indication of a sense of presence and engagement caused by the stereo effect after co-analysis of the questionnaire data (Rajae-Joordens et al., 2005). Then, in another example (*Half-Life 2*),

TABLE 1 A Summary of Game-Related Studies Introducing Potential, Empirically Derived UX Subcomponents. An x Indicates that the Authors have Considered that Subcomponent. The Main Scopes (Motivation to Play, Immersion, etc.) and the Methodologies Used Vary From One Study to the Next

	Method*	Number of participants	Skill, competence	Level of challenge	Emotions	Control, autonomy, freedom	Focus, concentration	Physical presence	Involvement, meaning, curiosity	Story, drama, fantasy	Social interaction	Interactivity, controls, usability
Jennett et al. (2008)	PC	260		x	x		x		x			x
Poels et al. (2007)	Qu	21	x	x	x	x	x	x		x	x	
Ryan et al. (2006)	QN	927	x		x	x		x		x		x
Sherry et al. (2006)	PFA	550		x	x					x	x	
Ermi and Mäyrä (2005)	PFA, Qu	234		x				x		x		
Lazzaro (2004)	Qu	30		x	x				x		x	
Sweetser and Johnson (2004)	PC, Qu	455				x		x		x		x
Takatalo et al. (2004)	PFA	232	x	x	x	x	x	x	x	x	x	x
Pagulayan et al. (2003)	Qu, QN	thousands		x	x							x

*Method: PFA = principal factors analysis, PC = principal component analysis, Qu = qualitative interview, QN = quantitative data collection.

heightened EDA in challenging episodes was related to challenge and tension after a coanalysis of the questionnaire data (Nacke & Lindley, 2008), and finally (*James Bond 007: NightFire*) to a wounding and death of the gamers' own character after coanalysis of the gamer behavior (Ravaja, Turpeinen, Saari, Puttonen, & Keltikangas-Jarvinen, 2008). The findings based on such coanalysis show that in FPS's EDA underlies a) presence and engagement caused by the stereo effect (Rajae-Joordens et al., 2005); b) an optimal flow experience (Nacke & Lindley, 2008); and c) fun in dying (when accompanied by the heightened facial muscle and electromyography measures; Ravaja et al., 2008).

The three different kinds of interpretations of the objective information presented above raise a question, what are the psychological processes causing the variation in EDA? This is a typical case of an inverse problem: how to determine unknown causes based on the observations of their effects (Alifanov, 1994). In each of the above examples, the interpretation of the EDA depends on the research paradigm chosen by the researcher (Ravaja, 2004). In this way, researchers associate physiological and psychological phenomena. But the challenging question still remains, whether these two measures just happen simultaneously or are strongly or even causally related to each other. The assumed relationships between physiological measures and psychological constructs are established in the laboratory with oversimplified stimuli (e.g., tone pips), and the strength of such association is not considered very high (Gómez-Amor, Martínez-Selva, & Román Salvador, 1990; Ravaja, 2004). That is why, for example, EDA measures are especially difficult to generalize to psychologically multidimensional phenomena in media environments, such as games. If psychological multidimensionality is in scope, then the participants themselves should interpret their subjective experiences. Here, we concentrate on the subjective research methods, such as interviews and questionnaires. In the field of behavioral sciences, the use of questionnaires has proven to be a valid way of assessing various mental phenomena (Breakwell, 2006; Rust & Golombok, 1999).

We have developed a Presence-Involvement-Flow Framework (PIFF; Takatalo, Häkkinen, Särkelä, Komulainen, & Nyman, 2004; Takatalo Häkkinen, Särkelä, Komulainen, & Nyman, 2006; Takatalo, Häkkinen, Kaistinen, & Nyman, in press) in order to integrate a vast number of relevant UX subcomponents into one framework and to study the UX in games as multidimensional, subjective, and psychological in nature.

Presence-Involvement-Flow Framework

The Presence-Involvement-Flow Framework (PIFF) is a psychological research framework devised for studying the UX in digital games. PIFF is based on the broad concepts of a sense of presence, involvement, and flow. Each concept includes subcomponents that are relevant both to the technical game components (e.g., mechanics, story) and the psychological determinants of the UX (e.g., cognitions, emotions, motivations).

The first version of the PIFF was based on two datasets ($N = 68$ and $N = 164$) and included 23 subcomponents (Takatalo, Häkkinen, Särkelä, Komulainen, & Nyman, 2004). Thereafter, more data were collected (2,182 participants) from various games (approximately 300), different displays (HMD, TV, CRT), and the contexts of play (online, offline, home, laboratory). This large and heterogeneous questionnaire data enabled deeper multivariate data analysis, which yielded 15 subcomponents. The resulting framework was, thus, called PIFF^2; it is composed of two separate parts, which assess *adaptation*, that is, presence and involvement (Takatalo, Häkkinen, Särkelä, Komulainen, & Nyman, 2006), and *flow* (Takatalo, Häkkinen, Kaistinen, & Nyman, in press).

Adaptation: Presence and Involvement

The adaptation portion of the PIFF^2 describes the way gamers willingly form a relationship with a digital game (Takatalo, Häkkinen, Särkelä, Komulainen, & Nyman, 2006). Theoretically, adaptation is based on studies of the sense of presence (Lombard & Ditton, 1997) and involvement (Zaichkowsky, 1985). Presence describes gamers' experience of being in the game world and its story and sharing this world with other agents. Involvement (Zaichkowsky, 1985) is considered a measure of the gamers' motivation, that is, how interesting and important they perceived the game to be.

The Big-Three subcomponents (Laarni, 2003) of presence include attention (psychological immersion), perceptual realness (naturalness), and spatial awareness (engagement; Lombard & Ditton, 1997). This threefold construct has also been reliably reported in empirical studies (Lessiter, Freeman, Keogh, & Davidoff, 2001; Schubert, Friedmann, & Regenbrecht, 2001). Additionally, the level of arousal and the range and consistency of physical interaction are integral parts of presence (Lombard & Ditton, 1997). In addition to physical presence, the sense of social presence has been recognized (Lombard & Ditton, 1997). Social presence is composed of social richness (the game as personal and intimate), social realism (the similarity to the real world), and co-presence (being there with others).

Involvement in adaption is defined as a motivational continuum toward a particular object or situation (Rothschild, 1984). Involvement concerns the level of relevance based on inherent needs, values, and interests attached to that situation or object (Zaichkowsky, 1985). Involvement is a central and well-established concept both in the fields of buyer behavior (Brennan & Mavondo, 2000) as well as in mass communication and mass media (Roser, 1990). It includes two distinct but closely related dimensions: importance and interest (McQuarrie & Munson, 1992). Importance is predominantly a cognitive dimension concerning the meaning and relevance of the stimulus, whereas interest is composed of emotional and value-related valences (Schiefele, 1991).

Taken together, presence and involvement indicate the shift between the real world and the game. Both are crucial when evaluating the fundamental technical game components, such as the interface and the narrative (Hunicke et al., 2004). Together, interface and narrative create a feeling of a place for gamers in which the action as well as the social interaction within the story takes place. Interface and narrative motivate gamers to pay attention to the game world that is provided (Sweetser & Wyeth, 2005). Although the range and consistency of the physical interaction in a game world are considered an integral part of the sense of presence, the interaction subcomponent did not fit in to our adaptation framework (Takatalo, Häkkinen, Särkelä, Komulainen, & Nyman, 2006). Instead, interactivity of the game was included in the flow framework along with the two other cognitive evaluations of the playing situation. These evaluations concern game mechanics (e.g., rules, goals; Hunicke et al., 2004), which affect the emotional quality in games.

Flow

Flow is defined as a positive and enjoyable experience stemming from an interesting activity that is considered worth doing for its own sake (Csikszentmihalyi, 1975). Thus, flow describes the subjective, qualitative, and emotional direction of the UX when participants are actively interacting with a game. Many factors have been related to this kind of optimal experience, such as clear goals and instant feedback (Csikszentmihalyi, 1990). In the core of the theory of flow is the interplay between the subjectively evaluated challenges provided by the activity and the skills possessed by the respondents. These are considered key cognitive antecedents, which are followed by different emotional outcomes. Different ratios between the evaluated challenges and skills are likely to lead to different emotional outcomes: A positive state of flow evolves through a cognitive evaluation in which both the skills and the challenges are evaluated as being high and in balance (Csikszentmihalyi, 1975; Takatalo, Häkkinen, Kaistinen, & Nyman, in press). The state of flow is often characterized by enjoyment and a positive valence (pleasure) as well as the absence of boredom and anxiety (Csikszentmihalyi, 1975). Flow has previously been related to playfulness (e.g., cognitive spontaneity; Webster & Martocchio, 1992) and the sense of control (Ghani & Deshpande, 1994; Novak, Hoffman, & Yung, 2000). In addition, a wide variety of other emotional feelings have been reported in games, such as impressiveness, amazement, and excitement (Lazzaro, 2004; Schubert et al., 2001).

Psychologically, the core idea of the flow theory (Csikszentmihalyi, 1975) is similar to cognitive theories of emotions (Ellsworth & Smith, 1988; Frijda, 1987; Lazarus, 1991). These theories support the idea that cognitive evaluations of events in the world are necessary parts of emotions. Various evaluations, such as the anticipated effort involved in a situation and the perceived obstacles, shape the emotions attached to these events (Ellsworth & Smith, 1988). In the theory of flow, the evaluation concerns the game challenges and the skills of the gamer. Also memory and previous experiences have an effect on the cognitive evaluation process and the evolution of emotions. Cognitive evaluations by the gamers and the related emotional outcomes provide useful subcomponents for analyzing the UX from the first moments of play to the completion of the game. Taken together, with theoretical and methodological strengths, PIFF^2 provides a state-of-the art measurement tool for analyzing the UX in games.

OBJECTIVES OF THE STUDY

The purpose of this study was to investigate whether the common belief of "the more stereo, the better experience" is true. In addition, we wanted to deepen the understanding of the added value of stereo in games. Thus, we analyzed a rally game, which was played with three different display disparities, namely, 2D, medium stereo separation, and high stereo separation. The UX was analyzed with a broad qualitative–quantitative hybrid method, which included PIFF^2, simulator sickness symptoms, qualitative open-ended questions of the gamers' descriptions of the game in all conditions as well as the possible downsides of the stereo effect in two stereo conditions, participants' demographic information, basic eye physiology, and objective performance in the game played. We also wanted to determine, whether demographic or other background variables had any effect on the UX.

METHOD

Participants

In the experiment, 91 university students (42 males, 49 females) were examined in a between-subjects design in which a driving game was played using three different stereo separation settings for the display (none, medium, and high). The mean age of the participants was 23.7 years (*SD* = 3.23 years). Most of the participants (85.7%) were fulltime students. The participants had various educational backgrounds; 23 different major subjects were represented. The most common majors were information technology (16.5%), psychology/cognitive science (12.1%), economics (11.0%), mathematics (8.8%), and biology (7.7%). The majority (68.3%) of the participants in either of the two stereo conditions (medium or high) had previous experience with stereoscopic images (films, autostereograms, or books).

Data Collection

PIFF² and simulator sickness

The EVE Experience questionnaire (EVEQ-GP) was used to measure PIFF². The questionnaire includes 139 questions (on a 7-point Likert scale and with semantic differentials) measuring 15 presence, involvement, and flow subcomponents (Table 2). These were divided into seven adaptation and eight flow subcomponents. In this study, the factor scores from each subcomponent were formed and used as a measurement scale. (To learn more about the origin and previous use of the PIFF², the reader is referred to our previous work: Takatalo, 2002; Takatalo, Häkkinen, Kaistinen, & Nyman, 2007, 2011; Takatalo, Häkkinen, Komulainen, Särkelä, & Nyman, 2006; Takatalo, Häkkinen, Särkelä, Komulainen, & Nyman, 2004, 2006).

Participants filled in the Simulator Sickness Questionnaire (SSQ; Kennedy, Lane, Berbaum, & Lilienthal, 1993) immediately before and after the experiment. The SSQ includes three different symptom dimensions: nausea, oculomotor, and disorientation. In addition, a total score can be calculated from the individual dimension scores. In the results analysis we used only those SSQ scores obtained after the experiment. We excluded two participants who had very high SSQ scores after the experiment. Both participants belonged to the medium stereo condition. The exclusion was done by detecting statistically significant outliers from the SSQ scores (a 95% significance limit). In addition, participants were able to report experienced downsides related to stereo displays in an open-ended question. An overview and frequencies of the most often mentioned downsides are reported.

Qualitative data

After the experiment, participants were asked to write down short descriptions and individual words about their playing experience. In this way, the gamers were able to describe how they perceived the game world, how they felt playing the game, and what the main reason for the described feeling was. Collecting participants' qualitative descriptions enables us to obtain a deeper understanding of the experiences gamers had. Such qualitative method has been utilized to analyze 3D stereoscopic movies (Häkkinen, Kawai, et al., 2008), demanding visual quality (Nyman et al., 2006; Radun, Leisti, Häkkinen, et al., 2008; Radun, Leisti, Virtanen, et al., 2010) and playing experiences in general (Komulainen, Takatalo, Lehtonen, & Nyman, 2008), for example. A large number of different descriptions was coded into 48 code classes with Atlas.ti software (Scientific Software Development, Berlin, Germany). For example, a code Reason (see Figure 1) included 17 descriptions, such as 3D graphics, stereo view [enhanced speed], third dimension [was fun], stereo display [made the environment more real or created a feeling of the game world], and display that immersed.

TABLE 2 Name, Number of Questions, Tarkkonen's Rho Reliability Coefficient, Short Description, and A Sample Question from each Subcomponent of the PIFF2

	Name and number of items		p	Description	Sample question
			ADAPTATION		
Presence	Role Engagement	12	.80	Enclosed by the role and place provided by the story	"I felt that I was one of the characters in the story of the game."
	Attention	12	.88	Time distortion and focusing on the game world	"I was not aware of my 'real' environmet."
	Co-Presence	14	.89	Feeling of sharing a place with others	"I felt that I was in the game world with other persons."
	Arousal	5	.70	Level of emotional arousal	"I was stimulated—I was unaroused."
	Physical Presence	17	.82	Feeling of being in a real and vivid place	"In the game world everything seemed real and vivid."
Involvement	Interest	6	.72	Value-related valences towards the game	"The game was exciting."
	Importance	8	.89	The meaning and relevancy of the game	"The game mattered to me."
			FLOW		
Cognitive evaluation	Competence	11	.86	Skilled with positive feelings of effectiveness	"I felt I could meet the demands of the playing situation."
	Challenge	5	.76	Game was challenging and required my abilities	"Playing the game felt challenging."
	Interaction	9	.72	Speed, range, and mapping of the interaction	"The game responded quickly to my actions."
Emotional outcome	Valence	10	.77	Positive valence, happy, not bored or anxious	"I felt happy—I felt sad."
	Impressiveness	9	.79	Amazed and astonished by the game	"I was astonished and surprised at the game world."
	Enjoyment	7	.77	Playing was pleasant and somewhat special	"I will recommend it to my friends" .
	Playfulness	9	.78	Feelings of flow and ease of doing	"I felt innovative."
	Control	5	.74	Feeling of being in control and independent	"I was dominant—I was submissive."

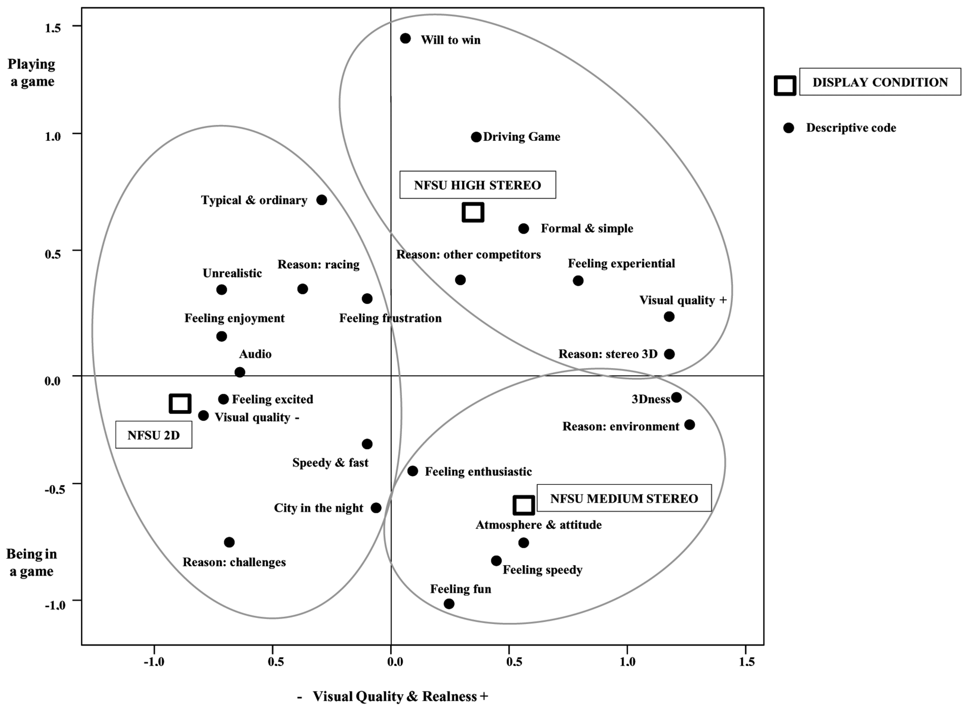

FIGURE 1 Correspondence analysis for the 24 descriptive codes and the three display conditions. The left side of the dimension one (X-axis) is characterized by good visual quality and realism; characteristic of the right side is poor visual quality. The upper end of the dimension two (Y-axis) represents typical ways of describing the playing of driving games, while lower end shows more the feeling of being in the game. The ellipses present the relationships between the display conditions and descriptive codes.

Each code class represents a dichotomous variable. If a participant has mentioned the issue included in the code, the participant is given 1 in that code, and if not the participant is given 0. Each of the 48 codes had at least 10 mentions among the participants. To ensure the reliability of the codes, another independent researcher coded the whole data set. Cohen's kappa coefficient (Cohen, 1960) was calculated for each code, and seven codes with a kappa value smaller than .61 were removed. Altman (1991) has stated that kappa values of .61 to .80 are good, and values above .80 are excellent. Values of the remaining codes in this study ranged between 66. and 1.00.

The remaining 41 codes were analyzed in a correspondence analysis (CA), which is a multivariate descriptive data analytical technique for categorical data. CA shares similarities with the principal components analysis, which applies to continuous data. CA is designed to explore simple two-way and multi-way tables containing some measure of correspondence between the rows and the columns. It is helpful in depicting the relationship between two or more categorical variables in a 2D spatial map, illustrating and summarizing similarities and differences between categories and the associations between them (Greenacre, 1984). Because finding such relationships from a 3-×-41 frequency table is rather challenging, we applied CA to depict how participants' descriptions and feelings (columns) vary in different display conditions (rows).

Participants' backgrounds

The background questionnaire included 40 questions consisting of general demographic items, stereoscopy- and technology-related questions, participants' susceptibility to sickness symptoms, and their overall feeling on the testing day. In this study, the following background questions were analyzed: age, general playing frequency, driving game frequency, driving game skills, attitude to driving games, motivation to play games, prior experience with computers, and computer use hours per week. The gender of the participants was balanced between the display groups beforehand. Although two participants with very high SSQ scores after the experiment were excluded, none of the participants gave the response "often" to the background question asking "How often did you get sickness symptoms in a car or a boat?". The purpose of this question was to detect persons who would be extremely susceptible to sickness.

Vision testing

Before the playing experiment began, each participant's vision was tested to ensure that participants would not have condition that would affect their ability to perceive 3D stereo or to increase the amount of symptoms. Basic visual functioning was measured with Snellen E-chart (far visual acuity), reading test (near visual acuity), and FACT near test (contrast sensitivity). Interpupillary distance was measured to check that none of the participants would have extremely wide or narrow distance between the eyes, as this might affect the perception of depth. Stereoscopic acuity was tested with a Randot test to exclude participants that do not have stereoscopic vision. Horizontal and vertical near phoria were measured with the Maddox Wing,[1] because in phoria the visual system needs to compensate for the slight misalignment of the eyes and, thus, high phoria values indicate that a participant might be more susceptible to eye discomfort. Furthermore, the relation between accommodative convergence and convergence were measured with the Maddox Wing. The function of the accommodation and convergence were further tested with the RAF gauge which measures the nearest point the eye can comfortably accommodate (the near point of accommodation) as well as the near point of vergence, which measures the nearest point to which the eye can converge without the stimulus becoming double.

A participant was excluded from the main experiment if his or her stereoscopic acuity was less than 60 arc per second, the horizontal phoria was more than 7D in an esophoric direction or more than 13D in an exophoric direction, the vertical phoria were more than 1D, the visual acuity was less than 0.80, and the contrast sensitivity was outside the 95% limit indicated in the FACT test. We also measured the near point of accommodation and the horizontal near-phoria after the experiment to detect any changes in the functioning of the accommodation and vergence systems.

Apparatus

All the participants used a Planar PE171/Planar SD1710 StereoMirror (Planar Systems, Inc., Beaverton, OR) monitor to play the game. The monitor consists of two different displays reflected on the same screen with a mirror. This is a binocular display providing a resolution of 800 × 600 pixels and a field-of-view of 30 × 30 degrees. The color quality was set at 32 bits, and the screen resolution, at 75 Hz. The computer used in the experiment was HP Compaq dc 7600 Convertible, Pentium 4 3.4 CPU at 3.4 GHz, with total memory 1000 MB DDR-SDRAM PC2-4200 (533 MHz), the display adapter ASUS EN7900GTX-512MB DDR3 (NVIDIA GeForce 7900GTX GPU), and the sound card Realtek ALC260 audio.

The stereo separation for the three display groups was set to 0 (2D, n = 31), 28% (medium stereo, n = 31), and 70% (high stereo, n = 29), based on the scale provided by the display adapter. The 28% condition represents a medium stereo separation, in which the disparity range of the game graphics varied between the display levels to 1.6 degrees in uncrossed direction. The 70% condition represents a high stereo disparity range of the game and the graphics varied between the display levels to 4.8 degrees in uncrossed direction. These disparity ranges were selected based on pilot testing with expert users. The subjects in all groups played the game wearing polarized glasses, and the setting for the three groups was similar in every way with one exception; the stereo separation was changed.

Statistical Analysis

Two distinct between-subjects multivariate analyses of variance (MANOVA) were conducted for both sets of PIFF^2 subcomponents (adaptation and flow) in order to control for the familywise Type I error. Significant differences in MANOVA were further studied in a univariate analysis. An additional multivariate analysis of covariance (MANCOVA) was performed to study the user background and eye physiology in more detail. SSQ dimensions were studied with univariate analyses of variance (ANOVAs). The inspection of the distributional assumptions crucial for multivariate statistical tests showed no univariate or multivariate outliers, and the normality, the homogeneity of variance-covariance matrices, and the correlations between the subcomponents used (a Pearson correlation ranged between .004 and .653) were all satisfactory. CA was used to analyze the qualitative data. All of the analyses were conducted with SPSS 15.0.

Procedure

Each participant played *Need for Speed Underground* (*NFSU*; Need for Speed Underground, 2003) for 40 minutes. *NFSU* is a first person driving game with a great deal of camera movement, numerous horizontal changes, and intense flux. The Microsoft sidewinder Gamepad was used to play *NFSU*. The participants were instructed to proceed at their own pace and, if possible not to ask for instructions while playing. However, they were assisted if they encountered insurmountable problems (i.e., technical or otherwise immediate disruptions). The task lasted for 40 minutes after which the subjects answered the questionnaires. During the game play, two objective performance measures were collected: the number of races attended and the winning percentage.

RESULTS

PIFF^2 and SSQ

Adaptation (e.g., involvement and presence) to a game differs among the three display conditions. The results of the MANOVA indicated a significant main effect for the display in all seven adaptation subcomponents (Wilk's Lambda = .72, $F(14, 160) = 2.05, p < .05, \eta^2 = .15$). The univariate ANOVAs showed no difference in either interest or importance between the display conditions (Table 3). Thus, the participants were equally involved and motivated to play the game. On the other hand, the gamers in a medium stereo condition experienced the sense of presence differently. Characteristic of the medium stereo condition was its power to create a feeling of being and acting in a real and vivid place (physical presence), being in a particular role (role engagement), and sharing the space with others (co-presence). Post-hoc testing (Tukey B) showed that the medium stereo condition was significantly higher compared to the 2D condition in all three presence scales ($p < 0.05$). The two stereo conditions differentiated significantly in physical presence and role engagement. The 2D and high stereo conditions did not have any significant differences. In addition, equal amounts of both arousal and attention were experienced in each display condition.

The MANOVA of the eight flow subcomponents revealed no statistically significant differences among the display conditions (Wilk's Lambda = .88, $F(16, 158) = .68, p = .81, \eta^2 = .06$). Thus, the participants evaluated their own competence, game challenge, and interaction in the game equally in each of the three display conditions. Consequently, the emotional quality of

TABLE 3 Group Means (M), Standard Deviations (SD), and ANOVA Statistics of the Adaptation, that is, Involvement and Presence Subcomponents in Three Different Display Conditions

	Experimental group							
	2D		Medium stereo		High stereo		*F*	η^2
PIFF[2] subcomponent	*M*	*SD*	*M*	*SD*	*M*	*SD*		
INVOLVEMENT								
Interest	−0.05	0.86	0.13	0.91	0.12	0.88	0.39	.01
Importance	0.03	1.03	0.24	1.13	−0.19	0.85	1.31	.03
PRESENCE								
Arousal	0.02	0.81	−0.10	1.01	−0.08	0.72	0.16	.00
Attention	−0.11	0.76	−0.17	0.69	−0.30	0.81	0.53	.01
Role Engagement	−0.27	0.89	0.28	0.80	−0.22	0.80	3.96*	.08

the UX measured with valence, impressiveness, enjoyment, playfulness, and control was similar in each condition.

There were no differences between the disparity conditions in adverse symptoms measured with the SSQ (total score, nausea, oculomotor, and disorientation). In addition to the SSQ, participants in the two stereo conditions were able to report possible downsides of the display used. Five participants in both the stereo conditions reported having eye problems. However, 12 participants reported having double images in the high stereo condition (3 participants in medium stereo) and 8 participants mentioned blurred or unclear vision (one participant in medium stereo).

Qualitative Data

The 41 codes composing the dichotomous variables of our qualitative data were analyzed in a CA. Similar to principal components analysis, CA provides orthogonal dimensions, which are extracted in order to maximize the distance between the row and column points (Greenacre, 1984). Usually, two first dimensions are used to create a spatial map, which depicts and provides useful information about nonlinear relationships within the data. In our case, the derived 41 codes concerning the gamers' descriptions of the game environment and their feelings about the game were used as column variables, and the three experimental display conditions were used as row variables.

Figure 1 presents the correspondence between the descriptive codes and the three display conditions. In order to clarify the output figure, those codes contributing to the point of inertia less than .020 in either of the two dimensions were removed. For the remaining 24 codes, we extracted two dimensions, with a proportion of 64% of inertia to the dimension one and 36% to the dimension two. The $\chi^2[46] = 104{,}0$, $p < .001$ supported the meaningful relationship between the row and column variables. The dimension one was named "Visual Quality & Realness," and the dimension two was called "Being in the Game–Playing the Game," according to the corresponding codes.

Figure 1 shows that both stereo conditions were evaluated more realistically and higher in visual quality compared to the 2D condition. The UX in the medium stereo condition was characterized by the nightly 3D city environment, speed, challenges, and the right kind of atmosphere and attitude. In the high stereo condition, 3D was also characteristic, but so was a feeling of competing and will to win. The game was characterized as being somewhat formal, a simple, typical, and ordinary driving game. Although the 2D condition was characterized as visually poor and unrealistic, it was still found to be enjoyable and exciting thanks to the challenges provided by racing. Also audio elements, such as the background music, were mentioned more in this visually poorer condition.

Background Questionnaires and Performance Metrics

The following background questions in three display conditions were compared: age, general playing frequency, driving game frequency, driving game skills, attitude to driving games, the motivation to play games, prior experience with computers, and computer use hours per week. Participants in the medium stereo condition were the most experienced with computers ($\chi^2[4] = 14.12$, $p < .01$). The participants in that group also reported the most hours of computer use per week ($M = 35.3$, $SD = 22.1$) as compared to the high stereo condition ($M = 21.6$, $SD = 18.5$) and the 2D condition ($M = 17.1$, $SD = 14.2$) (ANOVA $F(2, 85) = 7.70$, $p < 0.01$, $\eta^2 = 0.15$, Tukey B post hoc). The found background differences were further studied in an analysis of covariance (MANCOVA) along the other difference found in vision testing.

In each display condition, the participants finished approximately 17 races during the 40-minute playing session, of which they won an average of 22%. No significant performance differences were found among the display conditions.

Vision Testing

There were some differences between the experimental groups in the eye physiology measured. The right eye far and near visual acuity was divided into two equal-size groups (1.00–1.20 and 1.21–1.60). Participants in the medium stereo condition had significantly better vision in the right eye as compared to other groups ($\chi^2[2] = 8.86$, $p < .05$). In addition, the display groups differed in postexperimental exophoria. Only two participants in the medium stereo condition had post-exophoria as compared to ten participants in both the 2D and the high stereo conditions ($\chi^2[2] = 7.38$, $p < .05$). Thus, it seems that the changes in the visual system were not induced by the stereoscopic gaming, but caused by other reasons. This result is in agreement with other recent results obtained with stereoscopic movies (Fortuin et al., 2011).

A MANCOVA was performed on seven adaptation subcomponents, an independent factor being the display condition. Prior experience with computers, computer use hours per week, right eye far and near visual acuity, and post-exophoria were included as covariates. The covariates had no effect on the main effect of the display condition.

DISCUSSION

We have shown how different levels of stereo separation account for the UX in a first-person driving game. Three different display conditions, namely the 2D, the medium stereo, and the high stereo were investigated in a between-subjects experimental design with a hybrid qualitative-quantitative method. The method packet included a questionnaire of psychological playing experiences ($PIFF^2$), qualitative descriptions of the game environment and gamers' feelings about the game, negative symptoms (SSQ), open-ended negative aspects of the 3D stereo displays used, measurements of eye physiology and vision, background information, and objective performance metrics. Contrary to the widely held belief of "the more stereo, the better experience," both the questionnaire data and the qualitative descriptions indicated that the best experience was in the medium stereo condition. Medium stereo elicited a higher sense of presence (being in a real-like place, sharing the place with others) compared to the 2D or high stereo conditions. Thus, it is not stereo per se, but the right amount of it that makes the difference. The result can be understood in terms of the limits of stereoscopic vision: With larger depth magnitudes, the limits of stereoscopic vision are reached and blurred vision and even disruption of stereoscopic fusion occurs (Häkkinen, Takatalo, Kilpeläinen, Salmimaa, & Nyman, 2009; Howarth, 2011; Yeh & Silverstein, 1990), which disrupts the participants playing experience. However, in dynamic scenes the limits of stereoscopic vision can be flexible, as the eye can tolerate changes in camera separation (Ware, 1995). So, in games, the disparity limits are not strict but reflect a range of disparities affecting the UX in games.

Results showed no differences in experienced involvement or flow, negative symptoms or game performance between the groups. The found differences in eye physiology and user background between the groups had no effect on the main findings. The advantage of using multidimensional measures to evaluate UX, the added value of 3D stereo, and the practical implications of the results are further discussed.

THE QUALITATIVE–QUANTITATIVE APPROACH

Our findings support and deepen the previous findings in regard to the 3D stereo effect on the viewer. We utilized a method, namely PIFF^2, which is specifically designed to evaluate presence, involvement and flow in digital games. PIFF^2 showed that in the first-person driving game the medium stereo provides the best UX. Medium condition was optimal for the sense of presence, which three subscales (Physical presence, Role engagement, and Social presence) were consistently heightened. This finding was in line with the qualitative descriptions collected from the gamers as well as the way they evaluated the stereo displays: high stereo separation elicited unclear and blurry double images and thus hindered the UX. Although the involvement and flow measures showed no difference between the display conditions, new information about their relationship to 3D stereo content is provided. For example, 3D stereo had no effect on the emotional outcomes, that is, fun and enjoyment in games. In our case, the gamers' played a rather easy game, they were equally experienced, and they performed equally well in the game. However, this is not always the case. Subcomponents related to involvement and flow need to be understood when studying, for example, stereo effect in a critical first hour of playing a more demanding game. In such cases, meaning and interest, skill development and learning, as well as performance and challenges become issues. 3D stereo effect is complex and all its effects are not known yet. That is why 1D or simple measures, no matter how accurate they might be, do not capture the rich psychology related to UX in 3D stereo and multidimensional approaches, such as PIFF^2 are needed.

In order to control individual differences, we also studied user background and eye physiology. Some differences related to participants computer use (prior experience with computers and computer use hours per week) and in their eye physiology were found. Participants in the medium stereo condition were more experienced computer users, and they used computers more on a weekly basis. They also had better visual acuity in their right eye and no post-exophoria. In further analysis (MANCOVA), these background differences did not explain the heightened sense of presence in the medium stereo condition. Thus, the participants in the medium stereo condition were involved in other computer work than gaming, which was also seen in the nonsignificant differences between the display conditions and other game-related background variables (e.g., general playing frequency, driving game frequency).

Because presence has previously been associated with 3D stereo content (Ijsselsteijn, de Ridder, et al., 2001; Rajae-Joordens et al., 2005), we may ask, what it is in this concept that makes it so sensitive to 3D stereo and what is its meaning to the UX?

PRESENCE: EXTENSITY OF THE UX

Psychologists interested in the human experience have given experience many attributes, such as its quality and intensity (Wundt, 1897). These enable evaluating and understanding different perceptual experiences, for example, some experiences are good in quality and low in intensity whereas others are bad in quality but very intensive. Presence obviously impacts the UX in 3D stereo context, but what is the experiential attribute that is changing? One possibility is that 3D stereo has an impact on many experiential attributes, but the concept of *extensity* has been presented as one potential candidate for the spatial attribute of the experience in the early psychological writings (James, 1890). James (1890) further quotes Ewald Hering in describing extensity as an element of sensation, which distinguishes roomy from superficial and characterizes voluminous, vastness, massiveness, and bigness of an experience. Moreover, characteristics for an extensive experience are its scatteredness and spread in space (Titchener, 1929). For example, looking at falling snow from the distance is a totally different experience from being among the snowflakes where the three-dimensional location of each flake can be clearly seen (Barry, 2009; Sacks, 2006). In games and other media applications, proper measures of presence seem to indicate such enrichment, a natural and delicious deepening of the current 2D displays.

The three presence subscales we used (Physical presence, Role engagement, and Social presence) need to be studied more thoroughly in order to prepare a more precise tool with which to assess 3D stereo experiences in games. Stereoscopic vision has long been investigated through performance measures, such as the way it enhances depth perception and eye–hand coordination (McMahan et al., 2006; Treadgold et al., 2001). However, in entertainment context, it is a good idea to think 3D stereo in terms of experiential added value. This value is subjective in nature and as such it should be well designed to flourish its full experiential potential to the users.

PRACTICAL IMPLICATIONS

The game we used was a standard PC game, which was converted to 3D stereoscopic form with a display driver library. With this setup we could demonstrate that a medium amount of 3D stereo effect had a positive impact on the UX. This presents the first implication of the results: Like sound, 3D stereo is a special effect, which should not be used all the time with full intensity (Mendiburu, 2009). Second, it enhances some game scenes better than others, in other words, in some scenes it has no effect, and in some scenes it does not fit at all. This is well demonstrated with 3D stereo movies, some of which are especially designed for 3D effect. The best example of this is James Cameron's blockbuster *Avatar*, in which 3D stereo is used delicately in right places and with right amount. Scenes showing the floating mountains, flying with various animals and vehicles, and the shaping and coloring of the Pandora's vegetation are excellent examples of an effective utilization of 3D stereo (Anders, 2010). All these examples support that simple conversion from 2D to 3D is not enough. Currently, a careful study of the best utilization of 3D stereo effect is taking place in the movie industry. The game industry should follow this and start designing games especially for the 3D stereo format. In this way, the quality and intensity of the UX are likely to be affected, in addition to its extensity.

NOTE

1. Maddox Wing is a hand-held instrument that measures near heterophoria by showing different images to the left and right eyes. Seeing different images prevents stereoscopic fusion and the alignment of the eyes becomes visible.

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