Influence of Scenarios and Player Traits on Flow in Virtual Reality

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Abstract—Many studies have investigated how interpersonal differences between users influence their experience in Virtual Reality (VR) and it is now well recognized that user's subjective experiences and responses to the same VR environment can vary widely. In this study, we focus on player traits, which correspond to users' preferences for game mechanics, arguing that players react differently when experiencing VR scenarios. We developed three scenarios in the same VR environment that rely on different game mechanics, and evaluate the influence of the scenarios, the player traits and the time of practice of the VR environment on users' perceived flow. Our results show that 1) the type of scenario has an impact on specific dimensions of flow; 2) the scenarios have different effects on flow depending on the order they are performed, the flow preconditions being stronger when performed at last; 3) almost all dimensions of flow are influenced by the player traits, these influences depending on the scenario, 4) the *Aesthetic* trait has the most influences in the three scenarios. We finally discuss the findings and limitations of the present study that we believe have strong implications for the design of scenarios in VR experiences.

Index Terms—Virtual Reality, Player Traits, Flow, Scenario, Game mechanics

1 INTRODUCTION

CONSIDERING that one of the major challenge of Virtual Reality (VR) is to immerse users in a virtual environment, user experience has received much attention in VR research. Many studies focus on measuring how users perceive their interactions with the virtual environment, and tend to identify the factors that contribute to this experience. Although psychological processes are considered to be common to all humans, it is now well recognized that there are individual differences that might make it questionable to provide the same VR experience for everyone [1]. The user's subjective experiences and responses to the same VR technology can differ enormously between people [2], [3]. Previous studies have focused on cognitive factors [4], personality traits [3], [5], and other individual factors like gender and age [6], [7], to analyze their influence on users' subjective experience. They report different results, sometimes difficult to compare, and we assume that more studies in the domain should be conducted to investigate the role of specific users' characteristics on specific aspect of user experience.

In this paper, we therefore present an exploratory experiment where we investigate the link between users' player traits and the flow they perceive. Player traits correspond to users' preferences for game mechanics [8]. The impact of these traits on user experience, such as motivation and engagement, has been widely studied in the context of games and gamification [9], [10], [11], [12]. However, to the best of our knowledge, no study has been conducted yet on the impact of these traits on the VR experience. We argue that users may react differently to different VR scenarios depending on the game mechanics on which they rely. We developed three different scenarios in a same VR environment that rely on different game mechanics and propose to evaluate the influence of the player traits on users' feelings of flow in each scenario. Csikszentmihalyi [13] conceptualized flow as "the optimal experience", defined as "the holistic sensation that people feel when they act with total involvement". In the context of VR, Shin [14] defined flow as the mental state where complete involvement, enjoyment, and loss of one's senses of time and space are accompanied. As the flow felt by users depends on the task independently from the technological quality of the VR environment [14], we believe it may vary depending on the scenarios performed within a same environment.

Our main results are that the type of scenario and the order they are presented to the users have an impact on specific dimensions of the flow experience, several dimensions being higher when the scenario is performed last. We also highlight that almost all dimensions of flow are influenced by the player traits. Whereas the *Aesthetic* trait has rather positive influences on user flow in all the three scenarios, the influences of other traits depend on the scenario.

These findings have major implications for the design of VR scenarios to enhance user experience by considering individual preferences (players traits); providing affordances that support preconditions of flow; and allowing time for practice in the VR environment. In addition, flow should be considered as a complex construct composed of several dimensions, which are not impacted at the same way by

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the scenarios and not influenced equally (either positively or negatively) by the player traits.

2 Related Work

2.1 The role of inter-personal differences in VR

Although several personality traits and psychological variables are common to all people, it is now well recognized that there are individual differences that may impact user experience with VR [3], [15], [16]. Several studies have been conducted on the effects of interpersonal differences (internal factors) on subjective feelings of presence, degree of reality and immersion in virtual environments. Already in 1993, Slater and Usoh [17] studied users' subjective experience according to their representation systems (visual, auditory and kinesthetic) and perceptual position (egocentric or exocentric). Self-declared users as fast adapters reported higher sense of presence. More recently, Ling et al. [18] showed that immersive tendency and visual acuity of the right eye correlated consistently with presence in each of the three virtual environments the users experienced.

Several studies focused on the relationships between absorption and sense of presence. Baños et al. [1] found that both absorption and dissociation influenced central issues regarding reality judgment in VR. In line with this result, Sas and O'Hare [4] identified significant correlations between presence and cognitive factors such as absorption, creative imagination, empathy, willingness to experience presence, and cognitive styles. Sacau et al. [15] also found that absorption, domain-specific interest and agreeableness are good predictors of spatial presence. Finally, Kober and Neuper [2] showed that absorption seemed to be the best predictor for the feeling of presence; mental imagination, perspective taking, and immersive tendencies were significantly correlated with presence too. However, in another study, Murray et al. [19] found no correlation between presence and absorption (only between presence and dissociation, and between presence and locus of control).

Other studies were interested in users' personality traits. Laarni et al. [3] focused on personality-related differences and showed that extraversion, impulsivity and self-transcendence were positively associated with presence ratings. Jurnet et al. [20] investigated the influence of five user's characteristics (spatial intelligence, personality, cognitive style, computer experience and test anxiety) on the sense of presence; three of them (spatial intelligence, introversion, and anxiety) influenced the sense of presence experienced by the user. Weibel et al. [5] focused on the sense of immersion and its relation with the Big Five personality factors: openness to experience, neuroticism, and extraversion were positively related to immersive tendency. Dewez et al. [16] found that the locus of control is linked to several components of embodiment (the sense of agency is positively correlated with an internal locus of control and the sense of body ownership is positively correlated with an external locus of control). However, there were no correlation between personality traits and embodiment, which could appear rather contradictory with previous studies (if we consider embodiment as a sub-component of presence). As an explanation, the study conducted by Koper and Neuper [2] identified that personality variables like impulsive tendencies, empathy, locus of control, or the Big Five personality traits showed heterogeneous correlations with presence, depending on the presence questionnaire used.

A few studies focused on the effects of other individual factors like gender and age. Nicovich et al. [6] were interested in the effects of gender with respect to empathy and immersion. Their results indicate that both men and women appear to use empathic ability as a means of engaging in presence. Iachini et al. [7] studied the effect of gender and age on peripersonal (reachability-distance) and interpersonal space (comfort distance) in virtual and real environments: interpersonal-social (comfort distance) and peripersonal-action (reachability-distance) (similarly sensitive to social aspects) were moderated by gender (reduction with females; expansion with males) and age (expansion with adults; reduction with children).

All these studies report different, sometimes contradictory results. We thus can question the relevance of the personality traits studied in relation to the VR experience and we highlight the need for more studies in the domain to investigate the role of specific users' characteristics on specific aspect of this experience. In particular, no study has addressed yet the influence of users' player types. In this paper, we make the hypothesis that their preferences for some game mechanics integrated in the scenario may have an influence on their VR experience.

2.2 Users' preferences for game mechanics

Many VR applications rely on game mechanics that engage users in the scenario, such as interactions with other players (either collaboration or competition), self-representation into an avatar, or goal achievement. Player traits models have been proposed in the literature to distinguish such player preferences, arguing that people react differently when playing games.

Players generally have favorite game types, and they feel engaged with some game mechanics but not all. For example, Bartle [21] proposed a classification in four player types based on two axes that express the player's desire to interact with or act on the virtual world or other players: Achievers (acting on the world), Explorers (interacting with the world), Socialisers (interacting with other players), and Killers (acting on other players). This classification is one of the most well-known but is specific to massively multiplayer online role-playing games (MMORPG). More generally, Yee [22] identified three main motivation components: achievement, social and immersion. Based on a review of preview player type studies, Ferro et al. [23] also distinguish five player types: dominant, objectivist, humanist, inquisitive and creative. However, these typologies are not linked to practical tools (for instance a questionnaire) to identify users' player preferences for game mechanics.

Hamari and Tuunanen [24] conducted a literature review and a meta-synthesis of the existing player typologies and highlighted the lack of solid validation of the proposed models and argue for more research towards a definitive player preferences model. To meet this need, Vahlo and Hamari [25] proposed the Intrinsic Motivations to Gameplay (IMG) inventory for measuring intrinsically motivating gameplay, i.e. general motivations why people play games. They distinguish five factors: Relatedness, Autonomy, Competence, Immersion, and Fun. The three first factors are directly linked to the three universal needs identified in the Self-Determination Theory [26], [27] and are more general than just for games. The other two factors (immersion and fun) are not at the same level, and according to the authors could mediate the effect between the three first factors and gameplay enjoyment and appreciation. More recently, Tondello et al. [8] studied how people interact with games and are more or less motivated by the diverse game mechanics they experience. They aim to classify the different gameplay styles preferred for each player, instead of the general reasons why they play games. They propose a five player traits model, a player profile being a combination of several traits: Aesthetic, Challenge, Narrative, Goal and Social. They show evidence that these traits are actually related to different preferences when people play games, thus supporting the model's construct validity. We further develop this model in section 4.1.

In this study, we argue that there exists inter-individual differences in the users' VR experience according to their player traits and that these models, especially the latest proposed by Tondello et al. [8], can help understand users' preferences for game mechanics integrated in the scenario. We developed three different scenarios in the same VR environment that rely on different mechanics and propose to evaluate the influence of the player traits on user experience in each scenario. We more particularly focus on users' feelings of flow as defined in next section.

2.3 Flow in VR

Csikszentmihalyi [13] conceptualized flow as “the optimal experience”, defined as “the holistic sensation that people feel when they act with total involvement”. Flow comes from the balance between users' skills and the challenges and this balance has a positive and independent effect on the quality of experience [28]. If this balance is achieved, then feelings of pleasure, self-fulfillment and total control of the activity occur and are accompanied by a time distortion. It thus represents a highly enjoyable mental state where the individual is fully immersed and engaged in the process of activity [29].

Keeping users in a flow state is considered as one important goal in VR system design [30]. Shin [14] conceptualized flow experience in the context of VR according to the generally accepted definition: the mental state where complete involvement, enjoyment, and loss of one's senses of time and space are accompanied. VR appears to be adequate environment for users to experience flow: while experiencing interactive VR, most of a user's senses (e.g. sight, hearing) are purposefully directed to a specific context [31], which may facilitate a higher concentration on task and provide conditions for autotelic experiences and immersion.

Flow theory is widely used to study user experience in VR [32]. It allows researchers to assess the extent to which a user experiences a sense of immersion while using a technology [33]. In their literature review on immersive technology research, Suh and Prophet [33] showed that immersion, defined as a psychological process of engagement, has a positive influence on flow and/or presence [34]. In a recent study, Kim and Ko [35] showed that VR technology amplified sport spectators' flow experience to the greater extent than the traditional medium (2-D screen). Interestingly, the effects of VR technology on flow experience was stronger for those who are less interested in the target sport than highly involved sport fans. In their study, Faiola [36] identified that both flow and telepresence were experienced in virtual worlds (Second Life) and that there is a significant correlation between them. Experimental research also indicated that being in VR may foster deeper immersive experiences that improve individual creativity level, showing a significant correlation between the state of flow and the quality of the creative product [31].

Sweetser and Wyeth [29] developed a GameFlow model to evaluate users' perception of flow and improve game design. This model was enriched in 2012 [37] with a set of heuristics for designing and evaluating one specific game genre, real-time strategy games, each element including a set of criteria for achieving enjoyment in games. Rheinberg et al. developed the Flow Short Scale [38] to be combined with the Experience Sampling Method, a structured diary technique to appraise subjective experiences in daily life. Another scale named the Dispositional Flow Scale-2 (DFS-2), not specific to a domain, was proposed by Jackson and Eklund [39] to measure flow experiences in a certain context. Hassan et al. [40] relied on this scale and its dimensions to conceptualize flow in VR. They proposed an heuristic model of associations between preconditions of flow (challenge-skill balance, clear goals, sense of control, and unambiguous feedback) and all individual characteristics of flow (autotelicy, concentration on task, transformation of time, loss of self-consciousness and merging of action and awareness). Based on this model, they showed that experiences of flow in VR are associated with intentions to continue VR use and with longer VR sessions, although the association with the latter is perhaps of lesser strength. Finally, they underline that VR use should be the more natural and seamless so that users not feel discouraged.

Shin [14] distinguishes presence and flow as follows: ”Presence can be immersion into a virtual space, whereas flow can be an experience of immersion into a certain user action”. In our study, the technological features of the medium and the characteristics of the VR environment do not change depending to the experimental condition. We believe that the flow perceived by users will depend on the scenario and the actions users have to perform to achieve it. More particularly, and in line with the results of previous section, we investigate the extent to which player traits influence users' perceived flow according to a given scenario (and corresponding game mechanics).

3 Research Questions

Our study aims to analyze the influence of individual player traits on the user experience, and how it depends on the game mechanics integrated in the VR scenario. We more particularly focus on users' perception of flow. We therefore address two main research questions:

RQ1. Does the type of scenario have an impact on the flow experienced by users? As the actions performed by users may vary according to the type of scenario and related game mechanics, we hypothesize that the perceived flow may also vary.

RQ2. Do the practice and mastery of the VR environment (i.e. the order of the scenarios as they were presented) have an influence on user flow? As participants gain in VR skills at each scenario they experience, we hypothesize that it may have an influence on several flow dimensions, especially *Challenge-skill balance* and *Sense of control*.

RQ3. How does player traits influence the flow perceived by users? We perform a path analysis for each scenario to investigate to what extent, and in what ways, the different dimensions of flow are influenced by the different player traits.

4 METHOD

In order to answer the research questions identified above, we designed a protocol in which participants experience three different interactive game scenarios occurring in a same virtual reality environment. Participants' player traits are evaluated at the beginning of the experiment; then, after each scenario, participants are asked to rate the perceived flow.

4.1 Measurement of player traits

We identify users' player traits using the "Five Traits Model" proposed by [8] related to different preferences when people play games (see section 2.2). The authors propose a 25-item measurement scale for the five player traits. This scale outputs a player profile, which describes participants' preferences for different game elements and game playing styles. In our study, we therefore consider that players do not belong to a single player type, but that their player profile is a combination of several traits. The intensity of each player trait can range from 0 to 100 and these traits are independent. Here are the definitions [8]:

- *Aesthetic*: players who score high on this trait enjoy aesthetic experiences in games, such as exploring the world, enjoying the scenery, or appreciating the quality of the graphics, sound, and art style. On the other hand, players who score low might focus more on gameplay than on the aesthetic of the game;
- *Challenge*: players who score high on this trait generally prefer difficult games and hard challenges. On the other hand, players who score low prefer easier or casual games;
- *Narrative*: players who score high on this trait enjoy complex narratives and stories within games, whereas players who score low usually prefer games with less story elements and might skip the story or cutscenes when they feel that those get in the way of gameplay;
- *Goal*: players who score high on this trait enjoy completing game goals and like to complete games 100%, explore all the options, and complete all the collections. On the other hand, players who score low might leave optional quests or achievements unfinished;
- *Social*: players who score high on this trait generally prefer to play together with others. They enjoy multiplayer games and competitive gaming communities, whereas players who score low would prefer to play alone.

4.2 Measurement of Flow

We evaluate the flow perceived by users based on the Dispositional Flow Scale-2 proposed by [39] (see section 2.3). This questionnaire considers 9 dimensions of the flow experience:

- *Challenge – skill balance* : "Occurs when a person's skill is at just the right level to cope with the situational demands, which are above average for the person."
- *Action awareness* : "Involvement in the flow activity is so deep that it becomes spontaneous or automatic."
- *Clear goals* : "Goals in the activity are clearly defined (either set in advance or developed out of involvement in the activity), giving the person in flow a strong sense of what he or she is going to do."
- *Unambiguous feedback* : "Immediate and clear feedback is received, usually from the activity itself, allowing the person to know he or she is succeeding in the set goal."
- *Concentration* : "Total concentration on the task at hand occurs when in flow and the person do not think about unrelated things."
- *Sense of control* : "A sense of exercising control is experienced, without the person actively trying to exert control."
- *Loss of self-consciousness* : "Concern for the self disappears during flow as the person does not care about others."
- *Time transformation* : "Time alters perceptibly, either slowing down or speeding up. Alternatively, time may simply become irrelevant and out of one's awareness."
- *Autotelic experience* : "An autotelic experience is an intrinsically rewarding experience."

Each dimension is measured using 4 questions per dimension (likert scales from 1 to 7) for a total of 36 questions.

4.3 Virtual environment and game scenarios

Our objective was to design a virtual environment (VE) rich enough and interactive enough to allow the creation of engaging and appealing game experiences. Our VE represents a single-storey house with five rooms and a terrace (see Fig. 1). It includes a living-room, a kitchen, two bedrooms and a bathroom, all linked by a corridor. Around the house we created a montainous landscape. Every object is tangible, meaning the user can touch and apply force on them, and most of them are interactable (e.g., TV can be turned on, all closets and drawers can be opened) and/or can be grabbed (e.g., food, dishes, chairs, clothes, pillows).

Based on this environment, we developed three game scenarios, each one integrating at least one of commonly used game mechanics. The game design literature proposes a wide variety of game elements or game mechanics, with different granularity levels and different approaches. Some empirical studies propose classifications that group together game mechanics [41], [42]. To design our scenarios, we were interested in game mechanics that could be used in the same 3D environment and that would fit with VR scenarios (for instance moving in the environment or interacting with objects). Relying on these requirements, we selected the higher scoring mechanics that are common to both studies, namely Action-adventure, Role-playing and Exploration.

Fig. 1. Top-view of the virtual environment

We did not select social mechanics since we did not have the necessary infrastructure for the development of a multiplayer application. The three scenarios are illustrated by a video in the supplementary materials.

Exploration scenario: For this scenario, players have no objective and are free to explore the environment without any goal. To enrich the environment and make it propitious for exploration, we devised three versions of the VE: (1) the *neutral* one described above, (2) a *space* version and (3) an *horror* version. Players first spawn in the *neutral* environment and can then use a teleport point (on the TV) to successively visit the space and post-apocalypic dimensions. In the *space* dimension, the house is surrounded by planets and asteroids and the skybox represents far away stars. The shader used to render objects is changed to a unique shader with a holographic effect. The roof and floors shaders have a smoked glass effect, allowing the user to see through without feeling dizzy. The soundscape changes in favor of a sci-fi themed music. In addition to the aforementioned interactions, users in the space dimension can visit the terrace and are able to teleport on asteroids to get a top view of the house. In the *horror* dimension, the house is in (almost) complete darkness and the user has a flashlight at its disposal. The house is surrounded by a gloomy forest with high trees and fog. The floors shaders are modified to get a mossy effect, to accentuate the spooky ambiance of an abandoned house. There are also sound effects of a rocking chair and of wind in the trees.

Role-playing scenario: For this scenario, we specifically designed a story taking place in the virtual environment and a way to unveil it progressively to users during their experience. The player incarnates Ashley Silvery and follows the story of their uncle that disappeared recently. The story is distilled through pages of the uncle's diary that are unveiled one by one. In practice, the participants appear in the entrance of the uncle's house. They must read the first page of the diary to find out the rest of the story. When a page is detected as ”seen” by the application, a sound is played to indicate to the player that they can proceed to the next page and the path to follow is highlighted by ink stains appearing on the ground. The path is clear to users, so they do not need to mobilize explorer skills. At the end of the story, the user exits the house only to find it burning.

Adventure scenario: We designed a scenario which combines *adventure*, in the form of a simple quest, with some *action* components (zombie killing). Players are asked, at the beginning of the experience, to find 3 objects in order to build a bow. The objects are hidden so that users are required to interact with its surroundings. After finding each object, they get a notification informing them on the quest progression. When they achieve the objective, they are compelled to go on the terrace where a bow is waiting for them. This bow has to be used to kill 3 zombies that are walking towards the user. When searching on their surroundings, they can also find a fire torch giving them a boost for the last objective.

4.4 Apparatus

The virtual environments (VEs) were developed using Unity 2020.3.0f1 (Universal Render Pipeline) and the SteamVR plugin version 2.7.3. for managing interactions such as movements, teleportations and grabbing/interactions. The VEs were presented through an HTC Vive-Eye Pro head-mounted display (1440 x 1600 pixels per eye) and rendered using a high-end computer (CPU: Intel Core i5-9600K; GPU: RTX 2080s).

Participants were set up in a 2.5-meter square area where they could move their arms and turn around. To move in the virtual world, they could either walk in the physical area or teleport, but it was necessary to teleport into the virtual world to explore it in its entirety. The orientation and position of the headset and controllers were tracked by the integrated inertial sensors and the external base stations. The base stations were placed in two opposite corners of the area so the headset could be tracked regardless of the position and angle. Note that we also collected supplementary physiological data for future analysis: we used a galvanic skin response sensor (GSR) and a photoplethysmography (PPG) sensor to measure stress and heart beat, and we collected eye-tracking data provided by the HMD.

4.5 Procedure

Prior to the experiment a questionnaire was filled, offline, by registered participants to collect information about demographics, average video game-play experience and player traits (“Five Traits Model” presented in section 4.1).

Each participant experienced three VR sessions corresponding to the three game scenarios conducted in a given order selected among the six possibilities. Participants were distributed to the six possible orders so that to obtain a balanced number of participants for each possible order.

At the beginning of the experiment, before starting the first session corresponding to the first scenario, participants first read and signed a data-use consent form. Participants were then asked to view an instructional video, on a screen, that outlined how to use the controllers for movement and interactions in the context of the virtual environment. The investigator then helped participants to put the HMD on and guided them through the calibration of the headset using the built-in software (inter-pupillary distance and eye-tracking). When the participants gave their consent to start the condition, the investigator launched the application.

Before starting the first scenario, participants were first invited to practice previously learned controls in a specifically designed simple VE, allowing them to teleport and grab simple objects. Once they felt ready, participants were then teleported to the VE corresponding to the first scenario. At the end of each scenario (i.e., each session), participants removed their HMD and filled out the DFS-2 questionnaire on a computer. After a short break designed to avoid cybersickness and to break the immersion from the previous experience, participants proceeded to put the HMD back on to carry on with the second (and the third) session. In total the experience lasted between 60 and 90 minutes for each participant (between 10 and 15 minutes per session, plus explanations, training and inter-session breaks).

4.6 Participants

Participants were students from the university of Lyon in France, mostly recruited among engineering undergraduates. They were recruited by emailed calls for participation and using a simple online registration system. The exclusion criteria were a history of significant motion sickness, an inability to walk with ease, and a bad (uncorrected) vision. The number of participants was set to 48, so that each of the 6 different orders of conditions could be done by an equal number of 8 participants. A total of 144 VR sessions were thus conducted. The participants' age ranged from 18 to 31 years old with the mean being 21.38 (SD = 2.2) years. 32 were men (65%), 14 were women and 2 did not disclose their gender. Table 1 details their Gaming and VR experience, provided by the pre-test survey. Figure 2 details the distributions of their personality traits, as evaluated by questionnaire from [8].

TABLE 1
Gaming and VR experience of the participants (N=48).

VR Experience	Nb	Gaming Frequency	Nb
Beginner	29	Never	6
Initiated	12	Occasionally	19
Confirmed	2	Regularly	17
Expert	5	Frequently	6

5 Results

5.1 RQ1: Effect of the type of scenario on users' flow experience

To answer our first research question (RQ1), we specifically study the influence of the scenario (*Exploration*, *Role-Playing*, *Adventure*) on users' perceived flow. Since our data is not normally distributed, we employ Friedman tests (non-parametric equivalent of repeated measures ANOVA) for each dimension of flow (dependent variable) with the scenario as independent variable. We subsequently complete this analysis by Wilcoxon post-hoc tests (the non-parametric equivalent of the related samples t-test) with Bonferroni correction for multiple comparisons.

Figure 3 illustrates the distributions of scores for flow dimensions for which significant effects were found. All plots are available on the supplementary materials. On the one hand, Figures 3c and 3d show that the *Clear goals* and *Unambiguous feedback* flow dimensions have significantly lower scores for the *Exploration* scenario than for the other two scenarios. This means that participants had less precise objectives and considered the feedback of this scenario as less clearly defined than for the other two scenarios. On the other hand, the *Role-Playing* scenario is the one for which users perceived a significantly higher *Action awareness* (see Fig. 3b), meaning that they performed the actions rather "automatically", while the *Autotelic experience* was significantly lower than for the Adventure scenario (see Fig. 3a).

Therefore, with regard to RQ1: *"Does the type of scenario have an impact on the flow experienced by users?"*, our results reveal that the scenarios developed in the same VR environment have different impacts on specific dimensions of flow.

5.2 RQ2: Effect of the mastery and practice of the VR environment on users' flow experience

In this section, we specifically study the influence of the order of the scenarios as they were presented to the participants (1st, 2nd or 3rd order) (independent variable) on the different conditions of flow they perceived (dependent variable). Since our data is not normally distributed, we employ the same analyses as for RQ1. Note that, to deepen certain aspects of the results, we also conduct a similar analysis for each scenario separately. In that case, since samples are no more matched, Friedman and Wilcoxon tests are resp. replaced by Kruskal-Wallis and Mann-Whitney.

When we look at the results for each session order in Figure 4, we observe that the scores for the *Action awareness*, *Challenge-skill balance*, *Sense of control* and *Unambiguous feedback* dimensions significantly increase between the 1st and the 3rd order (see resp. Fig. 4a, 4b, 4d, 4e), with a progressive increase in the 2nd order. The same trend is observed with *Clear goals* (see Fig. 4c), with a close to significant increase between the 1st and the 3rd order (a significant difference between all three orders is observed).

To deepen this analysis, we observed the influence of the order for each scenario separately (see Fig. 5). The results reveal that the *Action awareness*, *Autotelic experience*, *Clear goals* and *Unambiguous feedback*, as well as the *Self-consciousness* flow dimensions increase particularly, with the order, for the *Exploration* scenario (p-values <0.5 or $\approx .05$). This means that participants needed more practice than for the other two scenarios (i.e. to perform this scenario at last) to clearly set their goals, perceive clear feedback on the activity, get really involved, be less concerned by the others and feel the experience as rewarding. Regarding the *Role-Playing* scenario, and considering the increase in the *Challenge-skill balance* dimension between the first and the second sessions (see Fig. 5f), we observe that participants needed more practice (at least two sessions) to feel competent when performing this scenario.

Therefore, in answer to RQ2: *"Do the practice and mastery of the VR environment have an influence on user flow?"*, our results confirm that the flow perceived by users depends on

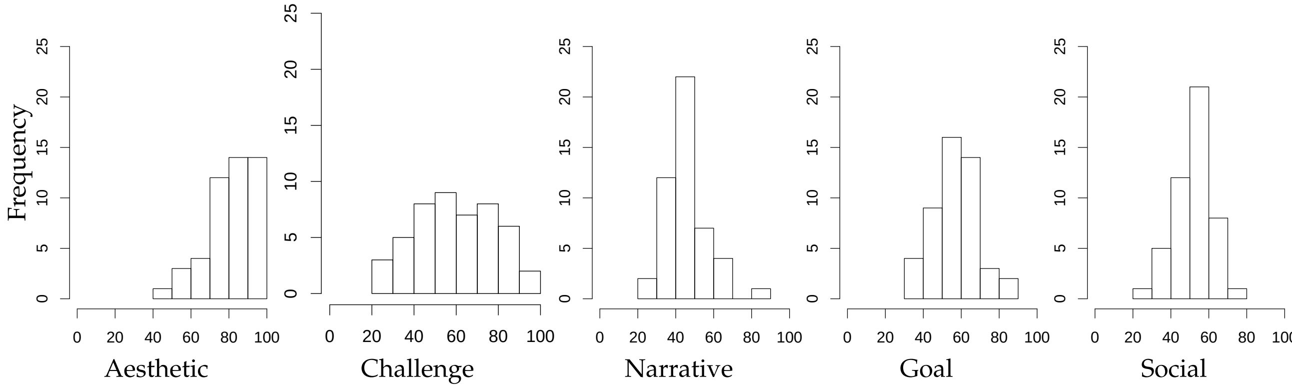
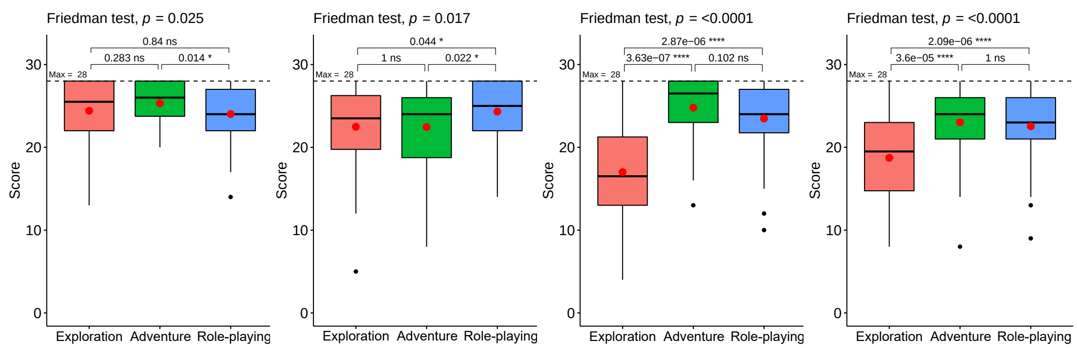
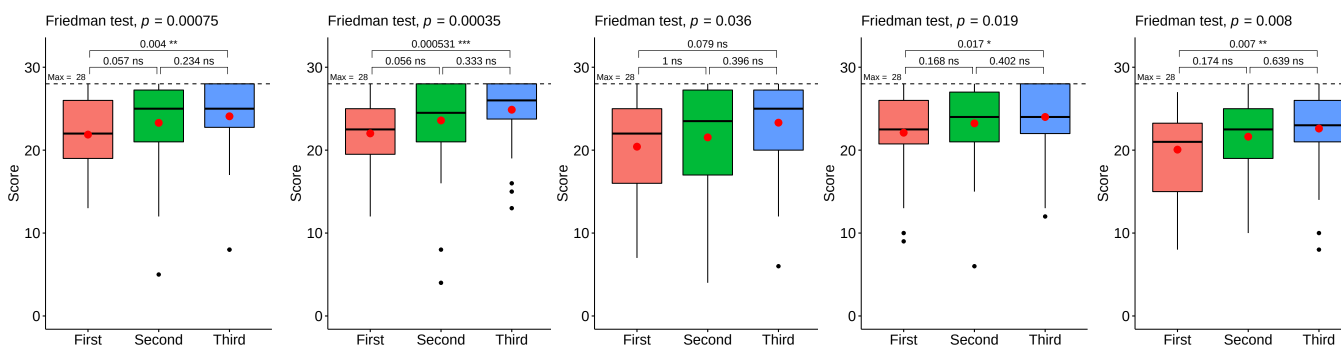


Fig. 2. Distributions of each player trait, evaluated by the questionnaire from [8]. Frequency refers to the number of participants that had a particular score.



(a) Autotelic Experience (b) Action Awareness (c) Clear Goals (d) Feedback

Fig. 3. Conditions for which significant effects of the type of scenario on user flow were found by Friedman tests. Results of Bonferroni-corrected Wilcoxon post-hoc tests (ns=not significant).



(a) Action Awareness (b) Challenge-Skill Balance (c) Clear Goals (d) Sense of Control (e) Feedback

Fig. 4. Conditions for which significant effects of the order of the scenarios on user flow were found by Friedman tests. Results of Bonferroni-corrected Wilcoxon post-hoc tests (ns=not significant).

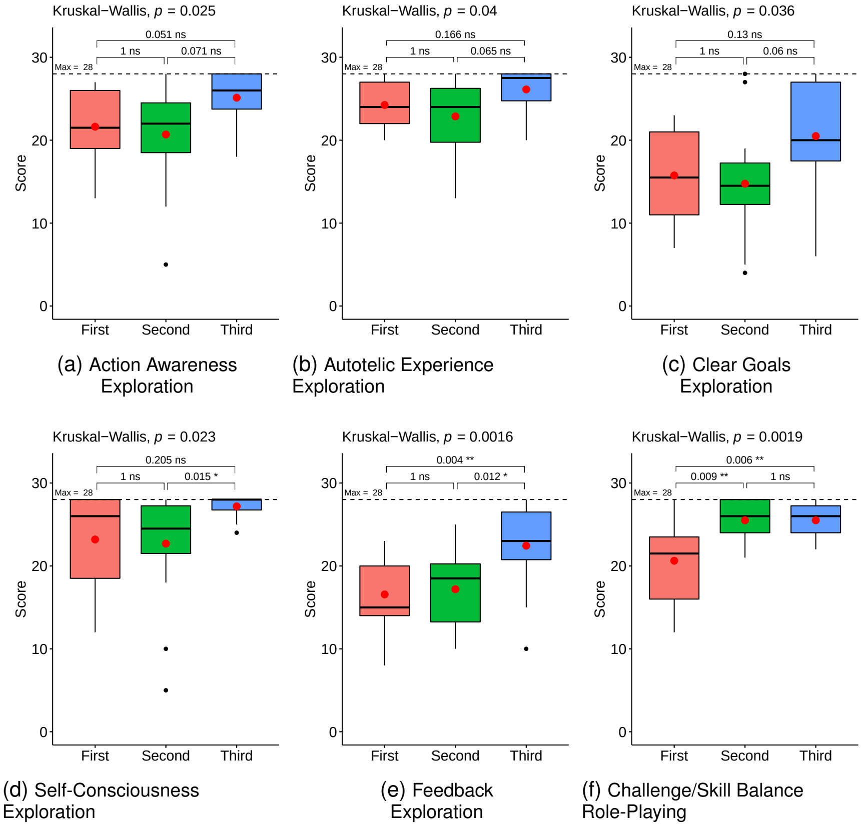
the order the scenarios are presented to them, and therefore on the time they practice the VR environment beforehand. Several dimensions of the flow experience are higher when the scenario is performed last, i.e. after performing the other two scenarios. Note that the impact of order is highly scenario-dependent and mainly concerns the preconditions of flow (*Clear goals*, *Unambiguous feedback*, *Challenge-skill balance* and *Sense of control*).

5.3 RQ3: Influence of player traits on flow

In answer to RQ2, we used the component-based Partial Least Squares Structural Equation Modeling (PLS-SEM) method in SmartPLS 3.0 [43] to identify the influences of each player trait on each dimension of flow. PLS-SEM is a method of structural equation modeling used to estimate complex cause-effect relationship models with latent variables. It has already been used in several studies on the influence of players traits on users' motivation and engagement in the gamification field [9], [10], [11], [12], [44], [45].

5.3.1 PLS path model assessment

Our path model is made up of 14 latent variables: 5 player traits and 9 dimensions of the flow scale per scenario (see



(a) Action Awareness Exploration

(b) Autotelic Experience Exploration

(c) Clear Goals Exploration

(d) Self-Consciousness Exploration

(e) Feedback Exploration

(f) Challenge/Skill Balance Role-Playing

Fig. 5. Per-scenario conditions for which significant effects of the order of the scenario were found by Kruskal-Wallis tests. Results of Bonferroni-corrected Mann-Whitney post-hoc tests (ns=not significant).

Figure 6). Each latent variable is defined by indicators (corresponding to questions): five for each player trait and four for each flow dimension. The latent variables come from the models (and related questionnaires) described in sections 4.1 and 4.2. Although the questionnaires had already been validated in other contexts, we nevertheless wanted to verify that they were also valid on our dataset. This validation relies on indicators' reliability, internal consistency reliability and convergent validity. We constructed and validated three path models, one for each scenario, considering that the values of flow dimensions vary according to each scenario.

Indicator reliability can be assessed through the factor loading estimates, which shows how well an indicator represents the underlying latent variable. It is generally advisable for factor loadings to be greater than 0.707, indicating that more than 50% of the variance in a single indicator can be explained by the corresponding latent variable. Somewhat lower values are acceptable as far as the latent variable validity and reliability criteria are met [46]. The internal consistency reliability is evaluated using composite reliability (CR). Researchers consider that values between 0.70 and 0.95 represent satisfactory to good reliability levels [43]. The average variance extracted (AVE) can be used to assess convergent validity. An AVE larger than 0.5 has been suggested to provide empirical evidence for convergent validity [47], [48].

We refined the model in two iterations to meet the convergent requirements of validity and reliability [43]. At a first iteration, after solving the equation and analyzing the results, we noted that the AVE of some latent variables were under the threshold of 0.5 and that some indicators did not show a high loading in their correspondent latent variable. We decided to remove in the three models all indicators with a coefficient under 0.4 in at least one of the models: two indicators for the *Aesthetic trait* (A3 and A4), one indicator for the *Goal* trait (G2) and one indicator for the *Challenge trait* (C2) were removed. At a second iteration, we removed the remaining indicator below the threshold of 0.5 (corresponding to the *Clear Goals* flow dimension in the *Adventure* scenario - CG3) in all three models. The convergent requirements of validity and reliability for the three models were met (all data are available in the supplementary materials).

We then assessed discriminant validity through the analysis of heterotrait-monotrait ratio (HTMT) of correlations that reveals to which extent a latent variable is empirically distinct from other variables. If the HTMT value is below 0.90, discriminant validity is established between two variables [49]. Most values of HTMT in our three models are below this threshold (see supplementary materials), meaning that the criteria is validated. Note that the values of HTMT between the *Unambiguous feedback* and *Clear goals* flow dimensions are above the threshold, meaning that they are highly correlated.

After this construction and validation step, we finally performed the path analyses for each scenario to identify the influence of each player trait on user flow. We run the bootstrapping procedure with 5,000 samples with percentile

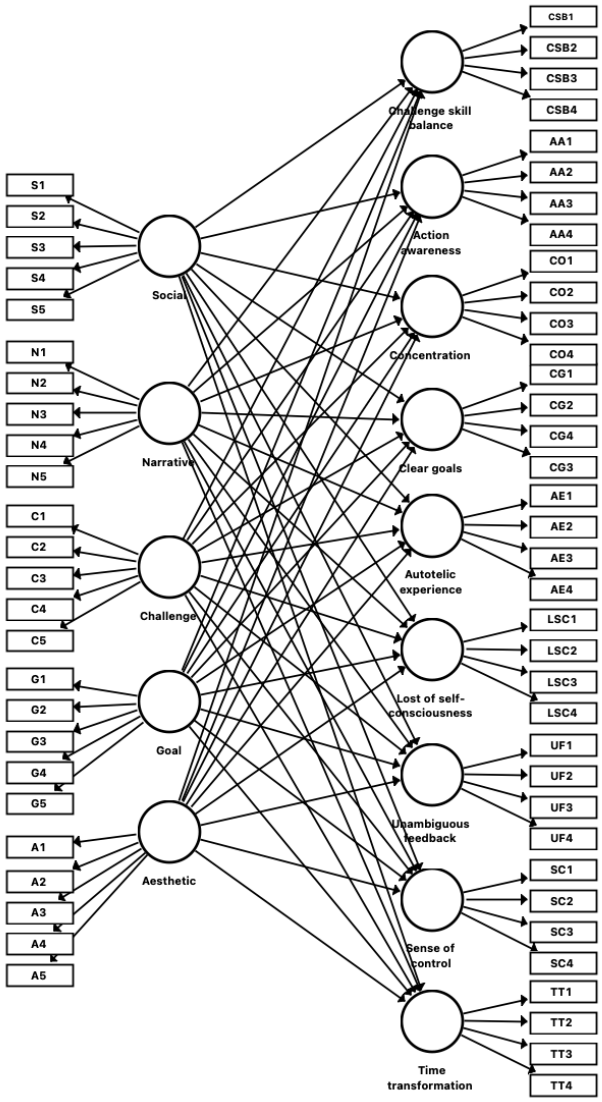


Fig. 6. PLS-SEM path model. Latent variables are represented by circles. Indicators are represented by rectangles.

bootstrap confidence intervals, and one-tailed testing at the 0.05 significance level (which corresponds to a two-sided 90% confidence interval). Table 2, Table 3 and Table 4 show the PLS path coefficients that reflect the influences of player traits respectively for the *Exploration*, *Role-Playing* and *Adventure* scenario.

We estimated the required sample size using the widely used minimum sample size estimation method in PLS-SEM: the "10-times rule" method [50], which builds on the assumption that the sample size should be greater than 10 times the maximum number of inner or outer model links pointing at any latent variable in the model. In our model it corresponds to a sample of 50 participants. Therefore, we assume that 48 participants is a reasonable choice.

5.3.2 PLS-SEM results

Regarding the *Exploration* scenario (see Table 2), the path analysis indicates that the *Aesthetic* trait has a positive influence on *Clear goals*, *Sense of control* and *Unambiguous feedback* (a tendency is observed on this dimension as $0.5<p<.1$). This means that a high score in this trait makes users perceive their goals, the quality of their actions and their performances as clearer, and feel in control. This trait makes also users have a high *Action awareness*, but a low perception of *Time transformation* (negative influence), meaning that they performed the activity rather "automatically", but without an alteration of their perception of time (either slowing down or speeding up). The *Challenge* trait has a negative influence on the *Loss of self-consciousness*, meaning that users who are highly challengers tend to be more concerned about the judgment of others during the VR experience (referring to the definition of this flow dimension in section 4.2). Finally, the *Goal* trait tends to have a positive influence on *Concentration*, meaning that it makes users be more concentrated on the VR experience.

For the *Role-Playing* scenario (see Table 3), the path analysis reveals only tendencies, with $p < .1$. The results show that the *Aesthetic* trait tends to positively influence the *Challenge-skill balance* and *Action awareness* flow dimensions. This means that users with a high score in this trait tend to feel more competent and involved when performing this scenario rather "automatically". We also find that the *Goal* trait positively influences the *Clear goals* and *Unambiguous feedback* dimensions, meaning that users who score high in this trait tend to perceive their own goals and the feedback on their actions and performances as clearer.

Regarding the *Adventure* scenario (see Table 4), we observe that the *Aesthetic* trait has a positive influence on the awareness of their actions, and the quality of the feedback they perceive. The path analysis also indicates two tendencies. First, highly *Challenger* users tend to be more concerned about what the others think (negative influence on the *Loss of self-consciousness*). Second, the *Social* trait tends to make users feel more competent when performing the scenario (positive influence on *Challenge-skill balance*).

Therefore, in answer to RQ2: "*How does player traits influence the flow perceived by users?*", all player traits (except the *Narrative*) may potentially have an influence on user flow and on all its dimensions (except *Autotelic experience*). This influence strongly depends on the scenario. The *Aesthetic* trait is the one that has the most influences on user flow and all influences are positive in the three scenarios, except for *Time transformation*. It is noteworthy that this trait mainly influences the preconditions of flow and *Action awareness* in all three scenarios.

5.4 Physiological data

As explained in the apparatus section, we collected physiological data with the objective to complement the results of questionnaires: galvanic skin response (GSR) and photoplethysmography (PPG). However, collected data were unfortunately too noisy to be exploited. The GSR sensor (attached to one of the participants' ears) was too sensitive to the head movement. For the PPG sensor, despite being installed on the non-dominant hand, the finger movements used to press the buttons also introduced destructive noise into the signals. Moreover, given the length of the experiment and the physical efforts made by the participants, the measured conductance was also influenced by body temperature regulation. We also collected eye-tracking data;

	Aesthetic	Challenge	Narrative	Goal	Social
Challenge.Skill.Balance	0.174	0.091	0.129	-0.137	-0,069
Clear.Goals	0.421	0.044	-0.184	0.128	-0.063
Unambiguous.Feedback	0.390	-0.167	-0.102	0.082	0.003
Sense.of.Control	0.449	-0.181	-0.006	0.035	0.064
Action.Awareness	0.373	-0.206	-0.047	0.015	0.056
Concentration	0.194	-0.160	0.164	0.289	-0.074
Loss.of.Self.Consciousness	0.134	-0.411	0.124	0.008	0.013
Time.Transformation	-0.347	0.090	-0.019	0.168	-0.053
Autotelic.Experience	-0.056	0.090	0.058	0.125	0.099

TABLE 2
PLS path coefficients for each player trait of flow dimensions for the *Exploration* scenario. Values in lightgray are not significant ($p > .1$), values highlighted in lightgray are close-to-significant ($p < .1$), values highlighted in gray are significant ($p < .05$). All p-values are reported in the supplementary materials.

	Aesthetic	Challenge	Narrative	Goals	Social
Challenge.Skill.Balance	0.420	0.129	0.148	-0.194	-0.168
Clear.Goals	0.307	0.012	-0.042	0.261	0.090
Unambiguous.Feedback	0.306	-0.080	0.005	0.276	0.144
Sense.of.Control	0.272	-0.023	0.010	0.147	0.010
Action.Awareness	0.374	0.150	0.170	-0.034	-0.124
Concentration	0.330	-0.097	0.155	0.060	-0.227
Loss.of.Self.Consciousness	0.272	-0.202	0.129	-0.127	0.126
Time.Transformation	-0.215	0.218	-0.104	-0.237	0.055
Autotelic.Experience	-0.064	0.260	-0.155	-0.029	-0.065

TABLE 3
PLS path coefficients for each player trait of flow dimensions for the *Role-Playing* scenario. Values in lightgray are not significant ($p > .1$), values highlighted in lightgray are close-to-significant ($p < .1$), values highlighted in gray are significant ($p < .05$). All p-values are reported in the supplementary materials.

	Aesthetic	Challenge	Narrative	Goals	Social
Challenge.Skill.Balance	-0.202	0.217	0.108	0.087	0.283
Clear.Goals	0.268	-0.158	0.106	0.111	-0.020
Unambiguous.Feedback	0.464	-0.066	0.031	-0.159	0.011
Sense.of.Control	0.344	-0.053	-0.251	0.238	0.178
Action.Awareness	0.466	-0.058	0.086	-0.198	-0.165
Concentration	0.267	-0.048	-0.023	0.217	0.082
Loss.of.Self.Consciousness	0.101	-0.254	0.176	-0.197	0.111
Time.Transformation	-0.168	-0.078	0.176	-0.183	-0.136
Autotelic.Experience	-0.086	0.211	-0.098	-0.098	-0.122

TABLE 4
PLS path coefficients for each player trait of flow dimensions for the *Adventure* scenario. Values in lightgray are not significant ($p > .1$), values highlighted in lightgray are close-to-significant ($p < .1$), values highlighted in gray are significant ($p < .05$). All p-values are reported in the supplementary materials.

however, since no toolbox still exist for the analysis of such data for full 3D 6DoFs experiences, their exploitation requires complex developments and are left out the scope of this paper.

6 Discussion

6.1 Different impacts according to the type of scenario

Our study first reveals that the three scenarios developed in the same VR environment can have different impacts on users' flow experience, which are consistent with the design choices made in the scenarios.

The *Exploration* scenario, which has the lowest score for *Clear goals* and *Unambiguous feedback*, was designed to be aimless, users had no specific tasks to complete, unless exploring the environment. We can assume that it could explain why participants had less perception of what they were supposed to do in the virtual world and how well they performed. In their study, Hassan et al. [40] also underline that exploratory activities in VR have less defined clear goals but still allow the emergence of flow. Regarding the *Role-Playing* scenario, the higher involvement in the flow activity compared to the other two scenarios could be due to the story that guided users in the exploration of the environment, making the activity rather automatic.

These findings are in line with Shin [14] who argues that the flow experience works independently from the technological quality, and relies on the game mechanics and the actions users perform in the scenario. Since the intention to continue using VR is associated with the flow experience [40], these results reinforce the fact that attention should be paid to the design of the scenarios, which can lead to different flow experiences.

6.2 Different impacts according to the mastery and practice of the VR environment

Secondly, we show that the impact of VR scenarios depends on the order they are performed, several dimensions of the flow experience being higher when the scenario is performed at last, i.e. after performing the other two scenarios. Interestingly, the differences are mainly observed on the four dimensions that have been identified as preconditions to experience flow in recent work conducted by Hassan et al. [40] who distinguish characteristics perceived of flow from preconditions in which it can be experienced (*Challenge-skill balance*, *Clear goals*, *Sense of control*, and *Unambiguous feedback*). This means that the more familiar users are with the VR equipment and environment, the more competent and in control they feel of their actions, have clear goals and feedback, and are therefore able to perform rather automatically (referring to the increase in *Action awareness*).

Assuming that the preconditions are the circumstances and the environment that lead to flow, it seems intuitive that the affordances offered by the different scenarios directly influence the time of practice required to feel in a flow state. This is especially the case for the *Exploration* scenario for which five dimensions of flow increased when performed at last. These include the two preconditions that were identified as lower than for the other two scenarios, reinforcing the fact that a minimum level of mastery is required in the VR environment to perceive clear goals and feedback for this scenario.

In the *Role-Playing* scenario, participants also felt less competent to follow the story when it was experienced at first. This may be due to the fact that it is the one that requires the most skills in VR (to cope with the equipment or to follow a story). After a first session, the participants were more familiar both with the equipment and the VR environment, and the story may be easier to follow.

6.3 Influence of player traits on flow depending on the scenario

Finally, our study reveals that player traits influence the flow experienced by users. While the type of scenario impacts mainly the preconditions of flow, almost all dimensions (except one) are influenced by the player traits.

A strong *Aesthetic* trait makes the *Exploration* scenario perceived as having clear goals and feedback, and users have a high sense of control and get deeply involved in the activity. This trait also has positive influences on the other two scenarios, regarding the level of mastery and action awareness for the *Role-Playing* scenario and clear feedback and action awareness for the *Adventure* scenario. Overall, this trait has an influence especially on the preconditions of flow and on the users' involvement in the task in all scenarios. According to the definition of this trait in the specific context of our study, these findings tend to confirm that the users with a high aesthetic trait enjoyed exploring the virtual world in all three scenarios. This is in line with the study conducted by Tondello et al. [8] who found significant correlations between aesthetic orientation with most of the game mechanics (including role-playing and action game mechanics).

We should note that using the three remaining indicators out of the five initially used to measure the aesthetic trait can therefore be seen as a slight variation on the original aesthetic trait, specifically focusing on the extent to which users enjoy exploring the virtual world. In line with this result, Tondello et al. [8] underline that the aesthetic orientation corresponds with *seeker* in the BrainHex [51] typology and to *explorer* in Bartle's typology [52]. This is consistent with our analyses, which identify more positive influences of this player trait on user flow in the exploration scenario (on four dimensions) than in the other two scenarios (on two dimensions for each scenario).

The only negative influence is observed on the perception of time, meaning that the more aesthetically oriented the players are, the more perceptible time is, i.e. users are aware of the time spent in the environment. We hypothesize that this may be induced by the experimental setting that constrains participants. We also observe that the *Challenger* trait has a negative influence in two scenarios (*Exploration* and *Adventure*) on the *Loss of self-consciousness* that we believe may be due to the presence in the room of the researcher in charge of conducting the experiment. In fact, some participants mentioned they were ashamed of their performance and felt judged by the investigator watching them. More studies should be conducted to evaluate the influence of experimental set-up on flow.

The positive influence of the *Goal* trait in the *Role-Playing* scenario on users' perception of their own goals, associated with a clear feedback on what they were doing, could be explained by the story that guided them in the activity and the exploration of the environment. This finding confirms the positive correlation of this player trait with role-playing games in the model of Tondello et al. [8]. The influence of this trait on the users' concentration in the *Exploration* scenario was not really expected, we hypothesize that users with this player trait should have been looking for collectable or optional quests in the environment, thus requiring high concentration.

Finally, the positive influence of the *Social* trait on the feeling of competence in the *Adventure* scenario could be explained by the integration of a part of action game mechanic with zombie killing. In fact, the action mechanic is positively correlated with this player trait in Tondello et al. model [8]. The fact that this trait did not influence any other dimensions of flow makes sense as the players were not able to interact with others or avatars. We might have expected this trait to have a negative influence, but it seems rather neutral in these different VR experiences. We can assume that the other traits are discriminating in this type of experience.

In conclusion, in line with previous studies, we show that the flow experience is a key component of the user experience in virtual reality and that flow is influenced by users' individual characteristics, more specifically their player traits. Another study conducted in the gamification domain [53] also showed that for some of the player types, game elements increased or decreased flow depending on learners' preferences for game mechanics [54]. However, in contradiction with these results, Oliveira et al. [55] found no differences between learners' flow experience depending on the game elements they used. Further studies are needed to understand the role of game mechanics in specific contexts such as VR.

6.4 Implications for design

Flow experience is a key component of user experience and our findings have implications for the design of scenarios in virtual environments. More particularly, we showed that the level of flow felt by a user in a VR experience depends on three factors: the scenario, the time the VR environment is experienced and the players traits.

The first recommendation for a VE game designer is to distinguish between the game environment and the scenario, more specifically the game mechanics integrated into the scenario. Indeed, different gameplays can lead to different flow experiences, and more specifically have a different impact on its preconditions (*Challenge-skill balance*, *Clear goals*, *Sense of control*, and *Unambiguous feedback*). It is therefore essential to bring together the preconditions for flow in the design of the VR experience with clear objectives, clear feedback to users on their actions, and an adequate level of challenge according to users' skills so that they feel in control. For instance, in our study the *exploration* scenario was the one that least met these conditions and the flow felt by users was lower than for the other two scenarios in several dimensions.

Second, we recommend designers to consider the time required for users to master the VR environment. Most studies in VR rely on a single unique experience, for which users may not have sufficient skills to feel confident with the VR environment, even if they can practice before the experiment. It would be necessary to immerse them into the environment and let them get to use it before they really get into the story, so that VR experience is more natural and seamless [40]. The more familiar users are with the VR equipment and environment, the more competent and in control they feel of their actions, have clear goals and feedback, and are therefore able to perform rather automatically (referring to the increase in *Action awareness* in the present study). This is even more the case for scenarios where the goals and feedback are deliberately less clear, such as the *exploration* scenario in this study.

Thirdly, scenarios lead to different flow experiences depending on users' player traits. Measuring the player traits of the targeted users before designing scenarios could help to predict the level of flow they will feel. For instance, in this study the goal trait is a significant predictor of flow, this trait having positive influences on several dimensions in the exploration and role-playing scenarios.

The final recommendation concerns mostly the specific field of experimental VR studies and particularly their observation and evaluation. Firstly, the presence of a researcher in charge of experiments can have a negative effect on users who have a strong challenger trait, so it is better to be outside the room. We have also shown that the level of flow should not be evaluated as a unique construct but as being composed of several dimensions, which are not impacted in the same ways by the scenarios and not influenced equally (either positively or negatively) by the player traits. The use of the Flow Short Scale proposed by Rheinberg et al. [38] (16 items), or the Short DFS-2 form [56] (9 items) instead of the long one, can facilitate this measurement.

6.5 Limitations

First, one limitation of our study lies on the panel of participants. We used a relatively low number of participants, which still allowed us to perform valid statistical analyses. It is well recognised that the PLS SEM method works efficiently with small sample sizes when models are complex [48]. In addition, there are more men than women and they were mostly recruited among engineering undergraduates due to recruitment difficulties for a long experience (60 to 90 minutes) and only few of them were experts in VR (mainly beginners and initiated). We should then extend our study to consolidate our results with a more diverse panel of participants. It is noteworthy that most of the participants had a strong *Aesthetic* trait, but this distribution corresponds to that obtained in other studies that rely on the same model [8], [57].

Second, we developed three game scenarios that rely on the commonly used game mechanics in VR experiences (action, adventure, role-playing and exploration). It would be interesting to conduct studies to investigate in more depth the effects of other scenarios and game mechanics on user flow.

Third, the results obtained are quite depending on the design choices made for each scenario. For instance, some elements of the *Role-Playing* scenario presented similarities to the *Adventure* scenario, such as collecting narrative elements. The *Adventure* scenario presented only a single main quest whereas players with a strong *Goal* trait enjoy to "explore all the options, and complete all the collections". As underlined previously, these choices were made to respect the time constraints due to the experimental conditions. In addition, we chose to not explore the social orientations as defined in [8] due to limitations in the infrastructure for a multiplayer application.

Finally, the measures used for flow are based on self-reported data. The use of objective physiological data could provide some interesting complementary insights. We also observe that two dimensions of flow are negatively influenced by two player traits and this may be due to the experimental conditions. More studies should be done on how to be as unintrusive as possible in the experimental protocol.

7 Conclusion

In conclusion, we conducted a study that addresses an important issue regarding the impact of different types of scenarios independently of external factors related to the VR environment. We highlight that the scenarios and the order they are performed have an impact on several characteristics of flow, especially its preconditions. For instance in the *exploration* scenario, some preconditions that are lower than in the other two scenarios significantly increased at the third session. Our findings also reinforce those of previous studies that demonstrate that individual differences, more particularly players traits, have an influence on the impact of the VR experience on users [3], [5], [16]. In the present study, four traits have an influence on almost all dimensions of the flow experience, with an *aesthetic* trait having the most influences on five dimensions of flow. Our future work will be dedicated to analyzing the impact of other types of scenarios and game mechanics on the flow perceived by users. We will also explore the influence of the social trait on flow with the presence of an avatar or other players in the virtual environment.

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