Towards End-User Customization of Haptic Experiences

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Abstract. A Haptic Experience may take many shapes or forms, ranging from simple UI notifications on a phone, to fully immersive multi-sensorial experiences. In this context, dedicated Haptic authoring tools have been flourishing and the literature on Haptic design introduced many concepts and guidelines to improve Haptic Experiences. In this paper, we propose to go beyond haptic design and explore the potential of end-user customization of Haptic Experiences. First, we discuss and extend a theoretical model of Haptic Experience. We revisit the proposed design parameters to account for the spatialized notion of haptic feedback and study the suitability of these parameters for end-user customization. Then, we detail a user study (n=52) exploring how users can customize different haptic effects (18 different effects) through haptic customization parameters, i.e., intensity and spatial density. Finally, our results indicate significant variability in these parameters depending on the context and provide directions for future user studies regarding haptic profile design determined by subjective data.

Keywords: Haptic Experience · User Customization · User Experience

1 Introduction

With the advent of virtual reality, immersive experiences and wearable haptic devices, the number of available haptic experiences has greatly increased in recent years. For example, haptic experiences for cinema [9], video games [18], entertainment [4], healthcare [2] and training [7]. In this context, while haptic research is strongly focused on the design and evaluation of haptic devices, and content creators craft these experiences based on domain knowledge, the user customization of such haptic experiences remains scarcely explored [16].

This paper explores how haptic feedback can be customized by end-users. A key element in this respect, is the concept of Haptic Experience (HX), which was defined by Kim et al. [12] as *"A distinct set of quality criteria combining usability requirements and experiential dimensions that are the most important considerations for people interacting with technology that involves one or more perceived senses of touch, possibly as part of a multisensory experience"*. This definition of HX resonates with the definitions of User Experience (UX) [17] and the Haptic Experience Design (HaXD) [15]. Focusing on user experience, Kim and Schneider [12] proposed a HX model, defining the building blocks of a haptic experience (design parameters), pragmatic factors necessary for positive experiences (usability requirements), hedonic factors that influence experience (experiential dimensions) and discussed personalization support to enable customization. However, while the design parameters, usability requirements and experiential dimensions have been explored in depth by the authors [12, 1], the actual user customization of the haptic experience has not been explicitly assessed. Some early works of Seifi et al. [16] explored the idea of end-user customization of haptic signals. Through an analysis of existing haptic tools, the authors defined a parameter space characterizing haptic customization tools and discussed user preferences within this space. While this work offers valuable insights on what constitutes a good haptic customization tool, it is explicitly focused on the design of haptic signals by non-hapticians for everyday devices and use (typically cellphone notifications).

In this paper, we investigate how end users, without background in haptics, can fine-tune haptic experiences in a simple manner and without completely overriding the sensations that the haptic designer wanted to convey. Such mechanisms are common practice with other sensory modalities such as vision and audio. For example, users can fine-tune brightness and contrast levels or adjust sound levels to maximize their user experience, while playing a video game or watching a film. Moreover, as highlighted by Zheng et al. [21], user preference is different for each user and could change with the time. The current user mood, the experience (e.g. video games, sports, horror movies, action movies) or also the context (e.g. immersive experience, casually enjoying a film), further motivates the need of end-user customization for haptic experiences.

First, this paper discusses the different haptic design parameters from the HX model of Kim et al. [12] and their suitability as a customization parameters. We also revisit the design parameters to account for the spatialized notion of haptic feedback which was not considered. Second, we detail a user experiment (n=52) exploring how users can customize different haptic effects (18 different effects) through the selected haptic customization parameters.

2 Related Works

2.1 Haptic Experience Design

A Haptic Experience may take many shapes or forms. It may be associated with different types of content (e.g. Audio, 2D video, 3D games, VR experiences) [6]. It may use different modalities (kinesthetic, vibrotactile, thermal, electrotactile, ...) [20], it may rely on one or more devices, each with one or more actuators [10] with potentially different capabilities. A Haptic experience may either be passive (i.e. pre-recorded HX not dependent on user interaction) [9] or interactive (where the haptic feedback depends on users' interaction with the system) or it may simply refer to punctual UI events such as cellphone notifications [16]. With such a wide range of possibilities in terms of haptic design, researchers have proposed various definitions of this task, along with guidelines and principles. In [16], the authors define "haptic design" as the process of creating haptic effects to be rendered by a haptic display. However, this definition is limited as it relates mostly to the creation of the signal itself it does not account for higher level considerations related to the overall user experience. In the context of film making, Guillotel et al. [9] introduce the concept of haptographers as the professional in charge of crafting the haptic signal, synchronizing it with the audio visual content and supporting movie creatives throughout the production of the film. Moreover, they defined the concept of haptic cinematography and haptic editing and provide principles to help haptographers in their creative process. While interesting, this description of the hapic design process remains centered on the movie creation process. Closer to this work, Kim et al. [12], proposed a definition of a Haptic Experience and defined a theoretical model of the factors that constitute a good HX. Part of their work focused on the categorization of the design parameters that are used by artists to craft HX. The authors proposed a classification and a high level definition of the parameters that artists can manipulate to influence the Haptic Experience. Authors further validated their model experimentally in order to use it for the evaluation of haptic experiences [1]. Yet, it remained open how users could use this model to customize haptic experiences.

2.2 Haptic User Preferences and Customization

The literature on haptic perception is broad [8, 11, 21], and has repeatedly demonstrated that haptic perception and comfort vary among individuals [14, 19], as haptic feedback might be processed differently. This inter-user variability, typically requires to undergo perceptual calibration protocols to ensure that the haptic feedback is perceived and is comfortable. For example, in the context of vibrotactile feedback for VR target acquisition, Lange et al. [13], asked participants to provide comfotable and effective feedback. Similarly, in the context of an electrotactile wearable system Vizcay et al. [19], explored different methods to calibrate the overall intensity perceived to ensure that the haptic stimulation was well perceived and unharmful for the users. However, user calibration is only intended to determine the range of parameters that are perceived effectively, and user preferences are not taken into account. Moreover, Zheng et al. [21], in the context of affective responses, observed high variability for haptic preferences. Interestingly, they also observed that these preferences may vary with time, mood, or the experience's context (Video games, sports, Horror movies, Blockbusters, etc).

Based on this same observation, Kim et al. [12], suggested that the haptic experience could be improved by giving the option to adjust the haptic settings based on user preferences. They propose to perform such customization by adjusting or disabling elements of their design parameters. They also point out that novices supported this idea of personalisation (or tunability) of the haptic experience. Customization was also explored by Seifi et al. [16] for Affective Tactile Messages. Through an analysis of existing design and customization tools, they defined a parameter space to characterize them. With a Wizard-of-Oz experiment, they reviewed user preferences to characterize what constitutes a good haptic customization tool. However, authors focused on the design and customization of haptic signals in a limited context (UI/cellphone notifications).

3 Design and Customization of Haptic Experiences

This section revisits the "haptic design parameters" proposed by Kim and Schneider [12], focusing on their suitability for becoming user customization parameters. However, before delving on the details of these parameters, we propose to split the definition of hapticians to make a distinction between two actors for the haptic authoring process, namely the haptic designer and the HX designer. The haptic designer's role consists in creating the actual signal associated to a haptic effect. For example, if the haptic effect is associated with audio visual content, the haptic designer typically uses the audio track as a basis to craft the associated haptic signal. For this process, the haptic designer is considered an expert of haptic technology with low-level knowledge. The HX designer on the other hand is responsible for creating the experience using the effects created by the haptic designer. For passive HX (i.e. pre-recorded HX not dependent on user interaction), its task will be similar to a film editor, filling the haptic tracks with the effects designed by the haptic designer to create a coherent multisensory experience. For interactive HX, its role is closer to a game designer, setting up haptic feedback based on timed media, user input or other interactions in the environment. Another example is the creation of a haptic icon library for notification purposes in a mobile plaform. In this case, the haptic designer will create the haptic icon library, while the HX designer will be in charge to associate the notifications with the haptic icons in order to convey the desired information. Finally, in both examples, we should also consider the end-user role, which should be able to customize the experience crafted by the HX designer.

3.1 Haptic Design Parameters

In [12], Kim and Schneider proposed a classification and a high level definition of the parameters that Haptic designers and HX designers can manipulate to influence the Haptic Experience. Here we revisit these high level descriptions to propose practical definitions of these parameters from an application and implementation standpoint.

Timeliness: It is defined as the "temporal alignment with other sensory outputs or prompt response to system events and input.". Timeliness describes both the synchronization between related haptic, audio and visual content as well as the designed response delay to interactions for dynamic and interactive environments. It is typically setup by HX designers to ensure proper coordination of the haptic, audio and visual events. It can be used to ensure that different events are rendered simultaneously, or on the contrary to introduce voluntary delays.

Intensity: It is defined as the overall perceived strength of feedback. The intensity corresponds to the magnitude of the haptic feedback. From a haptic signal perspective, this typically corresponds to the amplitude of the signal. This parameter can be compared to the volume associated to a sound. It is defined by the haptic designer when crafting the haptic signal and can be modulated by the HX designer by applying a gain.

Timbre: It is defined as the overall tone, texture, color, or quality of the feedback. This parameter describes the haptic signal itself, and it is strongly linked with the haptic actuators. It describes the characteristics of the signal such as the type of waveform (e.g., sinusoidal, square or triangle waves), the signal frequency, the duration or the envelope of the signal, etc. It is the job of the haptic designer to craft the haptic signal that defines the "timbre" of a haptic effect. HX designers, could also provide variations of the "timbre" in order to fine-tune it.

The final parameter **Density** is defined as the rate of haptic feedback, i.e., the amount of haptic effects produced within a given time. This parameter corresponds to the temporal density of the haptic feedback. It defines both the amount of haptic feedback defined by the haptic designer in a given effect as well as the rate of the haptic effects introduced by the HX designer for a given time period. The Density parameter defines “when” the effect is happening rather than “where” the haptic effect is being perceived. In order to remove any ambiguity, we propose to rename the Density parameter into **Temporal Density**, to better reflect the temporal dimension, and to introduce the following two parameters to further characterize the spatial dimension:

Location: We define it as the location on the body where the haptic feedback is rendered. This position can be defined either with respect to a given user geometric representation [5] or based the haptic device setup/configuration. For mono-actuator haptic setup, this parameter is strongly linked with the nature of the haptic device, as the device determines the location that will be stimulated (e.g. wearable or hand-held device). For haptic systems that can stimulate different locations (e.g. haptic-vest, multiple wearable devices), the HX designer can leverage this parameter to create rich spatialized haptic effects. For this parameter, it is important to differentiate between passive and interactive HX. For passive HX, the HX designer is in charge of defining the location of the haptic feedback to make it coherent with the rest of the experience (e.g. the associated audio visual content). For interactive experiences, as detailed in [5], the HX designer may choose to either constrain the location of the haptic feedback by creating egocentric effects (specifying the location of the feedback on the user) or let the the system determine the location of the haptic feedback based on user interaction with the environment (e.g. location of the collision with the user representation) by creating allocentric effects (the haptic effect is associated to an object in the environment).

Spatial Density: We define it as the spread of the haptic effect around its location, i.e. the amount of body surface that is stimulated during a haptic effect. The spatial density is solely linked with the spread of a single haptic effect (e.g. finger tip versus the entire hand). Concurrent haptic effects that stimulate different body areas will impact the Temporal Density, although each effect could have its own Spatial Density. This parameter is typically defined by the HX designer based on the nature of the haptic effect. For instance, for environmental effects (e.g. earthquake, explosion), the effect should be associated with a strong spatial density while local effect (e.g. located collision with a small object in the scene) will have a small spatial density.

The relevance of location and spatial density dimensions is strongly dependent on the number of actuators being used, or the on possibility to relocate the actuators over the users’ body.

3.2 Customizable Parameters

Customization is the action to alter an object or a system according to personal preferences, or specifications. In the case of HX, as suggested by [12], the customization can be performed through the modification of the design parameters of the haptic experience. The key factors that make any customization system efficient and engaging are easeof-use and ease-of-comprehension [16]. The system must be designed for end-user, i.e. the system should be easy to use and understand by non-experts. In [12], the authors stated that “Novices supported personalization through the lens of accessibility along with experts HE1, HE3, and HE4.”, highlighting the importance of accessibility for end-users. Each customizable parameter needs to be understood by users. The name of parameters should be unambiguous and be accompanied with a definition. The interaction with the customization interface should result in perceivable modifications of the experience to allow users understand the dimension being modified. However, although customization should allow end-users to personalize their experience, the customization space should be restricted to limit the impact on the experience. It is important to differentiate customization and designer systems. With their expertise, designers are responsible for the artistic component of the experience. Changes to the customization parameters must not alter the artistic vision of the designer. Besides the artistic aspect, designers oversee the creation of haptic effect to enhance experiences by creating meaningful haptic feedback. The meaning of the haptic effect must also be preserved after customization.

We propose here to discuss the different parameters introduced in subsection 3.1 and define which can be used for customization. First, **Timeliness**, **Temporal density** and **Location** are not proper candidates as they are fundamental constituent to the HX design itself and require a high level of expertise to fully comprehend and setup. These parameters should only be controlled by the HX designer. **Timeliness** defines the synchronisation between the haptic feedback and the rest of the experience (passive or interactive). It requires an advanced understanding of haptic editing principles to setup and would be difficult to fine-tune with a simple interface. The **Temporal density** is defined by the HX designer when arranging the different haptic effect throughout the experience. It is part of the artistic vision of the designer and as such, allowing the modification of this parameter would directly affect the design intention. Additionnaly, setting this parameter also requires a high level of expertise and fairly advanced designing tools: for passive HX, it is related to the editing process, and for interactive experiences, it affects the staging of the scene. For similar reasons, the **Location** parameter was not considered a suitable customization parameter. For interactive experiences, this parameter may be handled dynamically by the system based on user interactions and therefore can not be fine-tuned. For passive experiences (a playback scenario for instance), this location parameter depends on the choice of viewpoint made by the UX designer (camera vs main character for example). This parameter relates directly to the artistic vision of the designer and thus should not be customized by the end-user. Finally, the **Timbre** was also considered an inadequate candidate for a customization parameter. The timbre of an effect represents by essence the artistic vision of the haptic designer. Modifying it would not only corrupt this vision, it would also change the meaning associated to the haptic signal. Furthermore, the timbre parameter cannot be understood easily by a non-expert user as it requires low-level expert knowledge in signal processing and haptic design. On the other hand, **Intensity** and **Spatial density** are both easy to understand and easy to use. The intensity is expressed as a gain over the haptic signal (similar to the volume of an audio signal) and the spatial density as the spread around the effect location (defined with a radius). Both parameters are of clear interest for the end-users to fine tune the haptic experience based on their preferences. For both parameters, the designer can propose a default value that can be changed without affecting the meaning or the artistic vision of the haptic effects. Both Interestingly, the two paramters can be used at different levels to customize a single effect or to customize the full haptic experience. Moreover, limiting the customization process to only two parameters allow

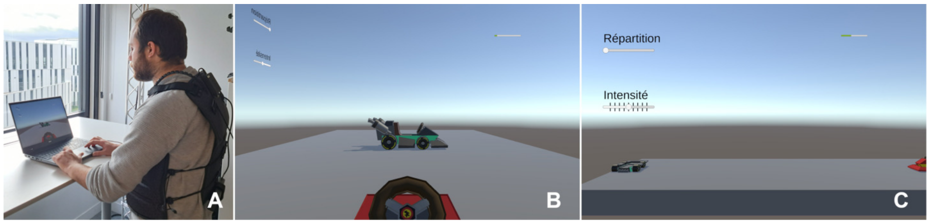

Fig. 1: User evaluation setup: the experimental setup (A), the user point of view of a scene playing out (B) and the user customization parameter sliders (C).

users to fine-tune the haptic experience while maintaining a reasonable level of effort and complexity.

4 User Study

This section presents a user experiment to assess how non-expert haptic users use the customization parameters in order to customize their haptic experience. To investigate the customization factors, we propose a go-kart driving scenario where users have to fine-tune the intensity and spatial density parameters in varied scenes (see Figure 1b,c). The main research question is to understand how users configure their haptic experience based on their preferences and the visual experience. Due to the nature of both parameters, we expected that there will not be a correlation between them, both expressing different dimensions of the haptic effects. Second, we expected that the customization for each go-kart scenario will be strongly driven by the nature of the event (e.g. crashing vs riding over dirt). Finally, we also expected that user preference will play a role when customizing the effects. In summary, our hypotheses were:

[H1] The intensity and spatial density are not correlated and both have a significant role in user preferences.
[H2] Intensity and spatial density will vary among different scene.
[H3] Mean intensity and spatial density customization will vary among users.

4.1 Apparatus and Participants

Figure 1a depicts the experimental setup. Users, were standing and equipped with a Skinetic haptic vest by Actronika containing 20 vibro-tactile actuators including 16 small actuators and 4 large actuators, 6 on the left front side, 6 on the right front side and 8 on the back, as shown in Figure 2. Visual stimuly was displayed using a 17 inch laptop, and the keyboard and the mouse was used for user input.

We recruited 52 participants (40 males, 11 females, and 1 other) aged from 18 to 60, with an average age of 30 to 40 years. Users rated their haptic experience with a 5-point Likert scale ranging from 1 "no haptic experience" to 5 "haptic expert". ($M = 3$; $SD = 1.4$).

Fig. 2: Distribution of the 20 vibrotactile actuators on the Skinetic haptic vest by Actronika. The vest contains two sizes of actuators. Small (red, 16): 4 on the left front side, 4 on the right front side and 8 on the back. Large (green, 4): one at the top front left, one at the top front right. And one on each side.

4.2 Experimental Design

Eighteen different go-kart scenarios were designed (see Table 1). The different scenarios lasted between 1 and 5.5 seconds. The main requirement was to provide a large variety of haptic effects covering different levels of the haptic design parameters. However, due to the nature of the scenario considered, we decided not to explore the "Timeliness" dimension, as all haptic effects were perfectly synchronized with the visuals. The "Timbre" dimension was also specific for each haptic effect, and selected by the haptic designer (one of the authors of the paper). Table 1 describes, for each effect, the level for each of the considered design parameters considered by the HX designer. For simplicity, discrete values are provided for each parameter. Intensity value was defined on the interval [0;1], where 0 means no haptic feedback, and 1 corresponds to the maximum device intensity. We use the following semantic :[0;0.35] *Low* intensity; [0.35;0.65] *Medium* intensity; [0.65;1] *Strong* intensity For Spatial Density, three levels were considered, *Small* (2-4 actuators vibrate), *Medium* (6-12 actuators vibrate) and *Large* (14-20 actuators vibrate). The exact number of actuators depends on the location selected by the HX designer. For Temporal Density, we considered 3 different levels: *Transient* (a single short of 22ms) effect, *Repetitive* (a transient effect played several times (2 to 6) over a couple of seconds), and *Continuous* (an effect lasting all the scenario).

For each haptic effect, users had to determine the preferred intensity and spatial density. Users were informed to fine-tune each effect to maximize the realism and their comfort. Thus, the main dependent variables were the values for each haptic design parameter, In addition, for each trial, we also measured the time the user required to perform the customization, and the number of clicks performed.

4.3 Experimental Protocol

The user study was divided in five main steps. (1) **Instructions**: Upon arrival, participants answered a short demographic questionnaire regarding the aforementioned data. Then, we briefed users regarding customization parameter definitions and the personalization

Table 1: Description of the haptic effects used in the evaluation. For each effect, the parameters defined by the HX designer are provided.

ID	Name	Description	Intensity	Temporal Density	Spatial Density	Location
S9	Football	The car hits a ball	Low	Transient	Small	Front
S14	Laser	The car goes through a red laser	Low	Transient	Small	Whole body
S15	Three balls	The car hits three balls	Low	Repetitive	Small	Front
S11	Haystack Collision	The car collider with haystacks. Two from the left and two other from the right	Low	Repetitive	Medium	Right and Left
S2	Drive on Gravel	The car is running on gravel	Low	Continuous	Small	Bottom
S7	Drive on Dirt	The car is running on dirt	Low	Continuous	Small	Bottom
S16	Haystack Push	You push a Haystack with The car	Low	Continuous	Medium	Front
S12	Rain	You are driving under the rain	Low	Continuous	Medium	Top
S3	Speed Bump	The car passes a speed bump	Medium	Transient	Medium	Bottom
S10	Portal	The car goes through a portal	Medium	Transient	Large	Whole body
S18	Bridge	The car goes over a bridge	Medium	Repetitive	Small	Bottom
S17	Lasers	The car goes through three red lasers	Medium	Repetitive	Small	Whole body
S5	Wood Sign Collision	The car collide with wood signs. Two from the left and two other from the right	Medium	Repetitive	Medium	Right and Left
S4	Barrier Friction	The car rubs against a barrier. First on the right side of the car, then on the left side	Medium	Continuous	Medium	Right and Left
S6	Close Barrier Friction	The car rubs against a barrier. First on the right side of the car, then of both side, then on the left side.	Medium	Continuous	Medium	Right and Left
S13	Car Fall	The car is falling to the ground	Strong	Transient	Large	Bottom
S8	Car Crash	The car crashes into another car	Strong	Transient	Large	Front
S1	Three Speed Bumps	The car passes three speed bumps in a row	Strong	Repetitive	Medium	Bottom

task with the following speech: “During this experiment, you will go through several scenes. For each scene, a specific haptic effect matching the visual on the screen will be rendered on the vest. Your goal is to adjust the haptic effect using two parameters in order to ensure that the effect is most pleasing to you. The objective is to adjust the haptic effect according to your preference. Your preference may be based on the perceived realism of the effect, (what you see matches what you feel), but it could also be related to the feeling that you may find pleasant. The two parameters that you will be able to adjust are "Intensity" and "Spatial Density". "Intensity" changes the vibration strength. "Spatial Density" changes the number of actuators vibrating on the device. The fewer actuators are used for the rendering of the effect, the more localized the effect is.“

(2) **Calibration**: The haptic vest was calibrated to ensure that all actuators were working and well positioned. Haptic effects are rendered on each actuator, and users must confirm the position of the haptic feedback for each of them. The goal here is not to find the minimum or maximum perception threshold of each user but to ensure that the device is well-placed on the user and that all actuators are working. Then, users practised with two random scenes and could experience customization tasks in modifying the intensity and spatial density with sliders. (3) **First Round**: Users customized each scene by interacting with two sliders, each representing the intensity and the spatial density of the haptic effect. Initially all effects are presented with the lowest intensity and spatial density. Each scene was presented in a random order. Once all the scenes are customized six random scenes were played in order to summarize their customization. At the end

of the round, users go through a "validation scene" with a summary of their choices represented by 6 haptic effects in a row. (4) **Second Round**: Users customized each scene again, but this time the parameters were initialized based on the customization of the first round. After all the scenes, six random scenes were played to summarize the final customization. The goal of this second round is twofold. It allows users to fix potential mistakes made in the first round and it also allows them to fine-tune each effect after the validation scene.

(5) **HX Questionnaire:** The haptic experience questionnaire [1] was administered to assess the user experience (5-point likert scale questionnaire). Users required around 25 minutes to complete the user study.

5 Results

In this section, we report the statistical analysis. We illustrate our results with figures depicting the correlation between parameters, the results per scene and the differences between users regarding intensity and spatial density. Only main results are presented and

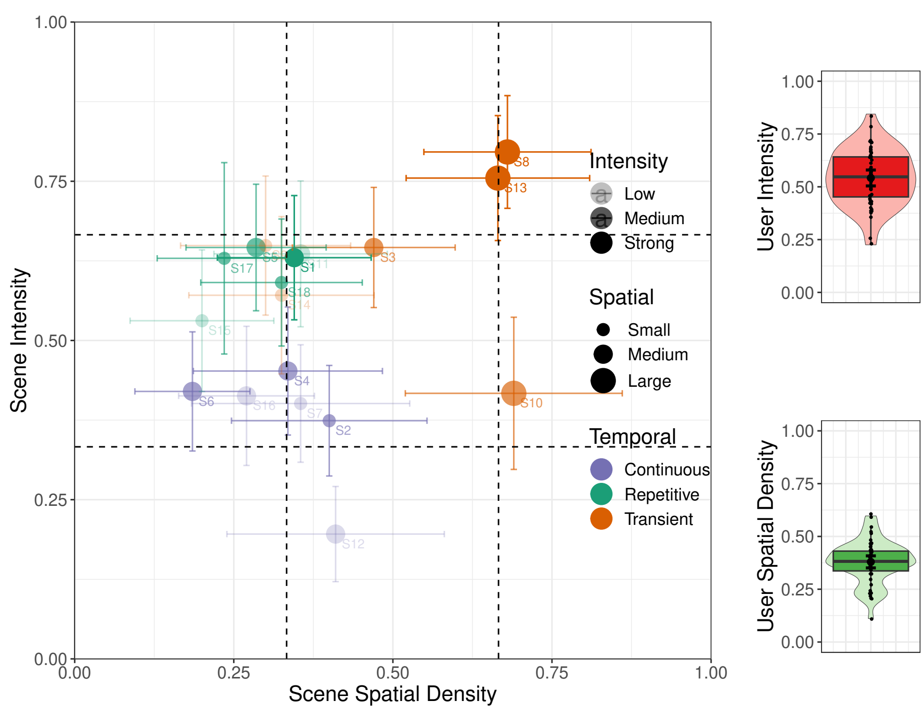

Fig. 3: Left, each dot represent the mean intensity and mean spatial density by scene, bars represent 1 SD. The non-spatial encoding, encodes HX designer parameters: the transparency encodes the intensity, the color the temporal density and the size the spatial density. Right, boxplots of the mean Intensity and Spatial density by user.

discussed. Two participants were removed from the statistical analysis as they constantly reported maximum intensity and spatial density.

Correlation between Intensity and Temporal Density. Spearman's correlation tests were used to investigate the relationship between customization parameters and between the designer and participants' results. We found no correlation between the intensity and the spatial density ($\rho < 0.01; n = 900; p = 0.67$), supporting **[H1]**. This result suggests that both dimensions are independent and that participants customized both parameters independently. Moreover, we observed that the number of parameters changes decreased in the second round, first round ($M = 4.8; SD = 0.87$) and second round ($M = 0.5; SD = 0.28$). We further studied the correlation between intensity and spatial density selected by the HX designer ($\rho < 0.52; n = 900; p = 0.001$). Therefore, the designer customized the haptic signal's intensity depending on the spatial density, unlike users who did not. These results might be due to the lack of haptic expertise reported by the participants. Nonetheless, this result tends to confirm our assumption that users customize their HX differently from designs. Moreover, we noticed a moderated inverse correlation between the scene temporal design and the intensity between users ($\rho < -0.41; n = 900; p = 0.001$). This result suggests that the longer the signal is, the lower the intensity is for users.

Scene Variability. Figure 3left summarizes the designer and customized user parameters for each scene. To study the intensity and spatial density variability between scenes, we performed a one-way ANOVA considering the Scene as an independent factor. There was a significant effect of the Scene on the signal intensity ($F_{9.81,480.49} = 41.58; p < 0.001; \eta_P^2 = .46$) and on the spatial density ($F_{10.01,490.60} = 17.74; p < 0.0010.226$). For both mean intensity and spatial density, pairwise post-hoc analysis (Tukey-Kramer corrections) revealed significant differences between group means, showing differences among particular scenes. Moreover, Figure 3left also shows the large coverage of the parameter space. These results partially confirm our hypothesis (H2) regarding differences between user customization parameters per scene. Moreover, the visual inspection of Figure 3left shows that any of the design parameters from the HX designer enables a perfect separation. Nevertheless, the Temporal Density seems to provide the best separation for both Intensity and Spatial Density. This suggests that sometimes the user customization will not fit with designer-expected values. For example, scenes S10, S12, and S13 matched with the user's mean values. Yet, scenes S6, S15, S9, or S1, did not correspond to the designer parameters. Further investigation would be necessary to identify variations in context and between designers and users.

User Variability. Figure 3right shows the mean normalized intensity ($M = 0.54; SD = 0.13$) and spatial density ($M = 0.38; SD = 0.1$) for each user (averaging all the scenes). These results cannot confirm our hypothesis (H3) regarding user customization variability. We witness a relatively important variability in intensity and spatial density, which testifies to potential variations within participants. However, a dedicated user study on interpersonal variations should be performed with various subjective variables such as mood, age, and haptic experience for the same device and scene.

HX Questionnaire. For simplicity, we only report mean, standard deviation and Cronbach's α values for each dimension: Realism ($M = 3.62; SD = 0.72; \alpha = 0.80$), Harmony ($M = 4.38; SD = 0.63; \alpha = 0.67$), Involvement ($M = 4.44; SD = 0.62; \alpha = 0.49$) and Expressivity

($M = 4.36; SD = 0.95; \alpha = 0.68$). In overall HX ratings are high for all dimensions, except for Realism which are moderate. The lower rattings for Realism can be explained by the limitations of vibrotactile feedback. Furthermore, as the used HX questionnaire has not been yet fully validated [1], we also report the Cronbach's α, which are below the recommended 0.7 threshold [3], except for the Realism dimension.

6 Discussion

Overall, our user study provided rich insight into user customization parameters and preferences. Thus, we propose a general discussion of these results and present our future works. First, the cross-correlation analysis shows a negligible correlation between intensity and spatial density parameters, indicating that these parameters are independent. Previous works in the haptic literature shows that intensity is a major parameter for the customization of vibrotactile experiences. Furthermore, in section 5, we witnessed that the number of parameter changes per scene significantly decreases between trials, i.e., an average of 5 to 0.4 changes per scene. Then, since spatial density and intensity are not correlated and the number of changes per scene decreases, while both parameters are equally used in each trials, we believe both parameters to be meaningful for user customization. It might confirm that users efficiently set their haptic preferences thanks to these two parameters. Hence, we assume that spatialization is an essential dimension regarding user preferences, which complements the intensity parameter in haptic user customization.

The following discussion focuses on these parameters' uses. We are investigating whether users could customize their experience by adjusting only one global setting for the whole experience, or if they need to have precise settings for each effect. Interestingly, we noticed that the customization of the haptic experience made by the users varied among scenes. Figure 3 shows important intensity and spatial density variations between scenes e.g. S12 and S18 in intensity and S10 and S8 in spatial density. These differences are partly explained by the designers' parameters choice, primarily because each scene has a different timbre, temporal density and location. Figure 3 also shows disagreement between designers' and users' choices for both parameters in ten scenes. Still, in Figure 3, we observe that "Continuous" scenes tend to get lower mean intensity values when compared with the other scenes. This outcome is strengthened by the highly negative correlation between temporal density and intensity. There is also a discontinuity between "Transient" haptic effects and the two other temporal densities. Overall, these results confirm that the scene context influences the haptic user customization, while it might be challenging to customize the whole experience with only one global setting. However, using a precise configuration for each haptic effect in the study seems complex. Future works should explore haptic effect classification based on the design parameters defined in [12] and extend them with the localization and spatial density. Such a classification could be helpful in designing a higher-level customization process based on the identified types of haptic effects. Extending the parameters might significantly ease the customization process by decreasing the time needed to personalize the experience.

Finally, we explored the haptic experience customization variation between users. Figure 3 (right) shows the mean for the intensity and spatial density per participant. We observed meaningful variations per customization parameters that we believe to be evidence of within-subject differences that might be a matter of further evaluation. Hence, we believe that, depending on certain subjective variables, we could identify user profiles according to the proposed customization parameters. Therefore, we plan to evaluate user preferences according to the context, the haptic experience, or the application domain, e.g., games or cinema.

7 Conclusion

This paper explored the customization of haptic experiences by first exploring the design haptic parameters relevant and second by describing a user study with the goal to explore how users will customize haptic experiences. The results suggest that signals' intensity and spatial density are not correlated and are suitable parameters for user customization. Moreover, our analysis reports variability between scenes and users. These results testify to potential interpersonal variation between users and the need of simple customization tools for haptic experiences. While in the proposed user study, users customized independently all the haptic effects, future works could explore how users could customize the experience following an effect-agnostic approach.

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