

# HFX Studio: Haptic Editor for Full-body Immersive Experiences

Fabien Danieau  
Technicolor  
France

fabien.danieau@technicolor.com

Philippe Guillotel  
Technicolor  
France

philippe.guillotel@technicolor.com

Olivier Dumas  
Technicolor  
France

olivier.dumas@technicolor.com

Thomas Lopez  
Technicolor  
France

thomas.lopez@technicolor.com

Bertrand Leroy  
Technicolor  
France

bertrand.leroy@technicolor.com

Nicolas Mollet  
Technicolor  
France

nicolas.mollet@technicolor.com

## ABSTRACT

Current virtual reality systems enable users to explore virtual worlds, fully embodied in avatars. This new type of immersive experience requires specific authoring tools. The traditional ones used in the movie and the video games industries were modified to support immersive visual and audio content. However, few solutions exist to edit haptic content, especially when the whole user's body is involved. To tackle this issue we propose *HFX Studio*, a haptic editor based on haptic perceptual models. Three models of pressure, vibration and temperature were defined to allow the spatialization of haptic effects on the user's body. These effects can be designed directly on the body (egocentric approach), or specified as objects of the scene (allocentric approach). The perceptual models are also used to describe capabilities of haptic devices. This way the created content is generic, and haptic feedback is rendered on the available devices. The concept has been implemented with the Unity® game engine, a tool already used in VR production. A qualitative pilot user study was conducted to analyze the usability of our tool with expert users. Results shows that the edition of haptic feedback is intuitive for these users.

## CCS CONCEPTS

• **Human-centered computing** → **Usability testing**; **Virtual reality**; **Haptic devices**;

## KEYWORDS

haptics; edition; full body; immersive experience

### ACM Reference Format:

Fabien Danieau, Philippe Guillotel, Olivier Dumas, Thomas Lopez, Bertrand Leroy, and Nicolas Mollet. 2018. HFX Studio: Haptic Editor for Full-body Immersive Experiences. In *Proceedings of ACM Conference (Conference'17)*. ACM, New York, NY, USA, 9 pages. <https://doi.org/10.1145/nnnnnnnn.nnnnnnn>

## 1 INTRODUCTION

The growth of Virtual Reality (VR) devices have enabled the creation of new types of immersive experiences: 360° videos, VR video games, virtual escape rooms, location base entertainment, or VR

laser tags. Such experiences set the user at the center of the content, who is represented by an avatar. Having an avatar greatly improves the immersion [9]. Indeed, research in VR has shown that being able to see and control a virtual body triggers a sensation of embodiment [21], even if this avatar does not fully fit the user's body [32].

While those experiences provide rich visual and audio feedback, the sense of touch remains poorly stimulated. Haptic feedback is often limited to the vibration of the hand controllers, commonly included in VR setups. The lack of devices and of editing tools may explain this situation. Nevertheless, haptics is still a very active research field. Various new types of devices have been designed: extended controllers [37], robotic arms simulating the contact with an object [35], ultrasound-based devices remotely touching the user [1], or vibrating vests. Very different sensations can therefore be stimulated: vibration, light pressure contact, or force-feedback for instance.

In this paper, we focus on the question of the creation and edition of haptic feedback. The challenge is to handle all the various sensations. They have their specific sensitivity threshold that also varies with the location on the body. Different haptic editors were already created but they address few sensations or few body parts [8]. Here we propose HFX Studio, an editor that illustrates the three contributions of our paper: i) a device agnostic edition of haptic sensations, ii) haptic perceptual models to encode haptic information, and iii) an egocentric and an allocentric editing mode. The aim of this approach is to create a single content that can be used with any existing and future setups. As a first step, the edition of tactile sensations (pressure, temperature and vibrations) is implemented.

The paper is organized as follows. Section 2 is dedicated to a review of the state-of-the-art graphical haptic editors. HFX Studio is then presented in Section 3. We have conducted a usability test in order to validate our concept and to identify potential issues. Protocol and results are presented in Section 4. Finally our approach is discussed in Section 5 and conclusions are provided in Section 6.

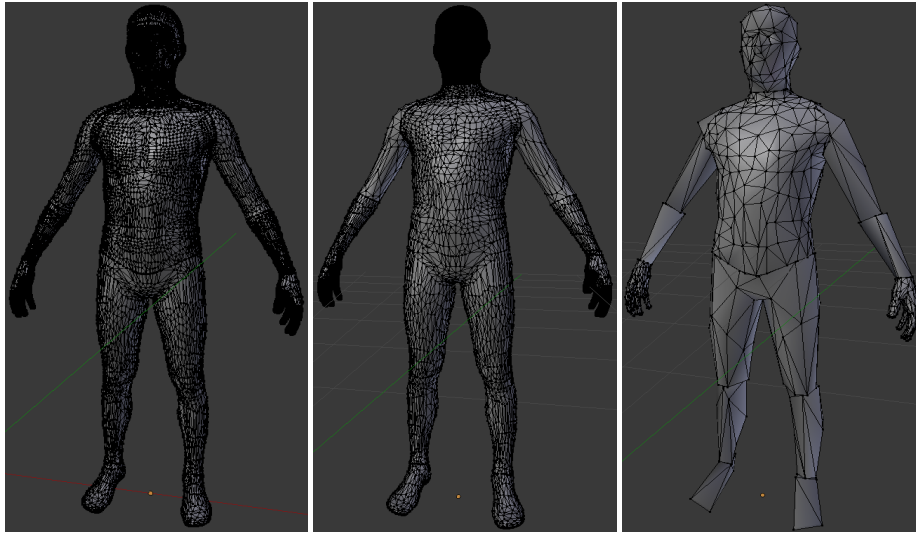
## 2 RELATED WORK

Haptic rendering algorithms were originally designed to reproduce realistic forces resulting from collisions. Then haptics has been applied to other applications with new requirements. For instance, haptics may be used to convey information where abstract movements of a knob represent "haptic icons". The Hapticon editor has been designed in this context and allows the control of the motion

*Conference'17, July 2017, Washington, DC, USA*

© 2018 Association for Computing Machinery.

This is the author's version of the work. It is posted here for your personal use. Not for redistribution. The definitive Version of Record was published in *Proceedings of ACM Conference (Conference'17)*, <https://doi.org/10.1145/nnnnnnnn.nnnnnnn>.



**Figure 1: Haptic perceptual models. From left to right: pressure model, vibration model and temperature model. Vertices density represents the two-point discrimination threshold.**

curve of this device [13]. Similarly, the posVib editor allows to edit vibration patterns [29]. It relies on a "perceptually transparent rendering" system that hides the actuator latency to the designer. Like the Hapticon, it features a curve editor but also provides a multi-channel system to control multiple devices. But the authoring of vibrotactile patterns on several devices can be a complex task. Thus, the tactiPED has been developed to simplify the editing by representing the shape of the end device [26]. It allows to better spatialize a vibration pattern. More recently, the Mango editor was proposed [30]. It focuses on the creation of spatial patterns for vibrotactile arrays: the designer intuitively draws a line or a curve that is rendered on a matrix of vibrators. The same authors developed the Macaron editor that allows the fine control of vibration curves as well as copy and paste features, and provides base samples [31]. The authors showed that the fine control of the vibration patterns in time enables the synchronization of vibrotactile feedback to audiovisual content (e.g. animation). The importance of the timeline has already been noticed by Cuartielles et al. [6]. The authors developed several iterations of visual editors for tactile patterns to come to this conclusion. They also suggest to represent the user's body on which a vibrotactile pattern is designed. They, however, do not provide details on the implementation.

In the context of entertainment applications, one would like to edit haptic feedback in a way similar that visual (aka VFX) or sound effects are authored. Numerous editors allowing to synchronize haptic feedback to movie frames have been proposed (see [8] for a review). They enable the design of force feedback [15][3], tactile patterns [23] or motion effects [7]. While most of these works allow the control of one specific device, other approaches relied on the MPEG-V standard to describe abstract haptic feedback [36][22]. Special tracks of vibration, temperature or other sensorial effects can be edited along a movie. Yet, this format cannot precisely locate the effects on the whole user's body.

Haptic authoring is also suitable for real-time 3D scene. The HAMLAT editor enables the tuning of haptic properties to virtual objects [12]: stiffness, damping, static and dynamic friction. This tool is a custom version of the open-source modeling tool Blender where haptic properties were added to the visual properties of a 3D object. A MPEG-V based version has also been proposed [11]. These two editors are device independent and thus describe abstract haptic features. An original approach is the Vibroplay where the edition is done within the virtual scene [17]. The represented user is directly "touched" by the designer to create the haptic effects. The edition is limited to arrays of vibrators though. Finally, the Immersion company has developed an editor combining the authoring of 3D scene and a multi-track system [28]. They relied on the Unity® game engine and developed a plug-in to edit vibration curves for popular video game controllers.

Hence, several works have addressed the edition of haptic feedback. It was often a solution to ease the control of a specific haptic device, but some works attempted to provide an abstraction layer to be compatible with any device. However, it seems that none of these tools considered the haptic authoring from the user's perspective. It is always about what the device will render and not what the user will perceive. Yet, the human perception will not change, and thus it is a good way to represent haptic sensation. Besides, with the growing number of VR experiences where the user is included in the scene, the design of haptic sensations based on the whole body is required.

### 3 HFX STUDIO

HFX Studio, is a haptic editor based on perceptual models to encode haptic information for a VR experience. The key challenge is to allow the design of multiple haptic sensations, at multiple locations on the user's body, that are synchronized with audiovisual content. In this work, a perceptual model is defined as a 3D mesh, carefully

designed, representing spatial haptic perception (currently vibration, pressure or temperature). Each perception has its own model. In addition, two editing paradigms are proposed: egocentric and allocentric. Haptic effects are set directly on the user, or haptic objects are added to the 3D scene.

### 3.1 Haptic perceptual models

The perception of a haptic stimulus is due to specific mechano or thermoreceptors. To represent unitary haptic perception cues [8], we designed three haptic perceptual models. Here we focused on the tactile aspect of the haptic perception (i.e. pressure, vibration and temperature) which properly illustrates the need of a body model. Besides most of the current haptic devices for mass-market VR systems rely on tactile technology.

We define a perceptual model as a mesh (i.e. a set of vertices) that represents the spatial acuity of a haptic perception (see Figure 1). The two point discrimination stimuli is usually performed to assess the spatial acuity. This way the haptic designer can select vertices to be stimulated. It would be then not necessary to define an effect between two vertices since it will not be felt. To design such models we used measurements from the literature in haptics.

The work of Weber and Weinstein provided valuable knowledge in the field of haptic perception [16]. Mancini et al. summarized their work and conducted similar experimentations [25]. These findings allowed us to define the body parts that compose our body models and the measurements to be associated to the pressure model. The body parts with their associated pressure acuity are: the head (7.5mm), the torso (12.5mm), the upper arm (from shoulder to elbow: 22.5mm), the forearm (elbow to wrist: 17.5mm), the hand (dorsum: 15mm, palm: 7.5mm, fingertips: 2.5mm), the upper leg (from belt to knee: 23mm), the lower leg (from knee to ankle: 27.5mm), the foot (back: 17.5mm, sole: 7.5mm). The definition of a perceptual model is challenging because perceptual thresholds may vary with age or gender. In addition, the spatial acuity is assumed to be homogeneous in our model although Mancini et al. suggest that a gradient of thresholds can be considered between joints. Our representation is suitable for this first approach since the lowest threshold of the body part is used. The limitations of the models are discussed in Section 5.

Vibrotactile acuity has been less studied than the pressure acuity. The previous measurements are often used for spatial vibration thresholds although the perception of vibration differs from the perception of pressure. Indeed vibration propagates along the skin, and depends on its temperature [5]. Frequency of the vibration also influences the perceptual threshold [14], it is lower near joints because the bones better propagates the vibrations than the flesh [20]. We kept the body parts defined above and relied on studies from the literature to identify the corresponding thresholds. Perception of the vibration on the head depends on the location of the stimulus [10]. Different distances were reported, we selected the shortest: 2.5mm. Perceptual threshold on the torso varies from 20mm to 30mm (it is lower for the middle line where the skin is thin [14]). 20mm was selected in our model. Perceptual threshold on the forearm is close to 25mm while on the arm it is 50mm [5]. On the palm, it is 10mm and the fingertips are still very sensitive with an accuracy of 2mm [4]. The hand dorsum is a little bit less sensitive:

16mm [38]. Regarding the lower body, few data exists. Upper legs threshold seems sensitive up to 30 mm [4]. We decided to apply the same value for the lower leg. We decreased the threshold for the foot dorsum (20mm) and for the foot sole (10mm).

While a body map of perceptual thresholds for cold and warm stimuli exists [33], the spatial acuity of such stimuli is the less documented. It is actually not trivial to define them since the perceived temperature depends on the stimulated surface [18]. Actually, the first goal of this sense is to maintain the body temperature, not to finely identify spatial temperature cues. Cain showed that the spatial discrimination is poor but attempted to identify spatial thresholds [2]. The head appears to be sensitive up to 50mm. The sensitivity on the torso would also be higher than 50mm. The forearm is less accurate with a threshold of 150mm. Since no data are provided for the upper arm, we kept the same value: 150mm. Jones indicated that the hand dorsum is sensitive up to 19mm [19]. We used this value for the whole hand in our model. Finally no data is available for the lower body parts, thus we kept the value for the arm: 150mm. More psychophysical studies should be conducted in order to refine this model. Nevertheless it poses the bases of a first model for temperature acuity while being compatible with the density of the current thermal displays (i.e. Peltier elements [27]).

To create the models, we used the generic human mesh of the Autodesk Mudbox software with a very high density. The space between vertices is about less than 2mm, and the height of the mesh is 180cm. It was imported into Blender and groups of vertices were selected to represent the different body parts. Then, for each part, the decimate tool was run to reduce the density of vertex until a mean target distance was reached. Table 1 shows the mean distance for each group.

**Table 1: Haptic perceptual models. Mean distances between vertices in mm, and corresponding standard deviations.**

Model	Pressure	Vibration	Temperature
head	7.72 (3.50)	2.62 (1.22)	48.8 (22.8)
torso	13.0 (6.94)	20.1 (10.4)	50.4 (24.6)
upper arm	22.3 (14.3)	50.9 (31.0)	150.4 (86.3)
forearm	15.3 (12.6)	25.5 (19.5)	150 (87.63)
hand dorsum	15.2 (10.4)	16.1 (10.7)	20.0 (11.0)
hand palm	7.2 (4.56)	10.0 (6.10)	20.0 (11.0)
fingers	2.59 (1.64)	1.93 (0.69)	20.0 (11.0)
upper leg	25.2 (16.2)	30.0 (18.4)	149.0 (82.1)
lower leg	27.6 (19.1)	30.5 (21.0)	155.5 (89.9)
foot dorsum	17.3 (9.0)	20.5 (10.4)	147.7 (62.8)
foot sole	7.58 (4.7)	16.1 (10.7)	147.7 (62.8)

### 3.2 Authoring interface

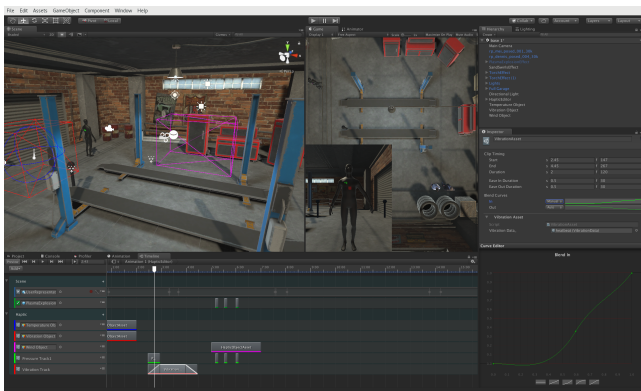
Based on the models described above, we designed a graphical user interface to allow user friendly authoring of haptic feedback. The design of such interfaces has been thoroughly studied by Schneider et al. in the context of vibrotactile feedback [30]. They proposed requirements for the development of tactile editing tools, which are applicable to other types of haptic feedback. Two sets of requirements were identified: literature requirements and industry

requirements. They were taken into consideration during the creation of HFX Studio.

Literature requirements gather height specifications from previous research works: real-time playback; load, save and manipulate; library of effects; device configuration; multiple channels (i.e. multiple effects) and combination of effects; visual/direct control metaphor; audio/visual context (i.e. synchronization to other sensorial modalities); user feedback (i.e. allowing quick prototyping and visualization of effects).

In addition to these requirements they interviewed experts to identify six industry requirements: animation window (i.e. fine control in space of haptic effect); timeline; object tool (i.e. haptic effect considered as an object that can be translated or scaled); path tool (i.e. motion of the object can be stored); haptic rendering schemes (i.e. configuration of the haptic rendering); global parameter tools (i.e. overall configuration of the haptic feedback such as the intensity).

Our goal is to propose a tool allowing the haptic edition independently from any device. Besides our haptic content must be synchronized to audiovisual content. To do so, our implementation is based on Unity®[34], a framework already used in video games and VR productions (see Figure 2). Since version 2017, it features a timeline system allowing the organization of animations, camera shots, audio sequences or particle effects in time. The system is not limited to linear scenarii though. Multiple timelines can be created and triggered when necessary. We have extended this timeline system to support haptic effects. Thanks to this tool, most of the listed requirements are fulfilled: timeline, audio/visual context, multiple channels, load and save, library of effects, object tool, path tool. Device configuration is also supported (see section 3.3.1). We developed two interaction paradigms to enable the edition of haptic feedback: egocentric effects and allocentric effects.



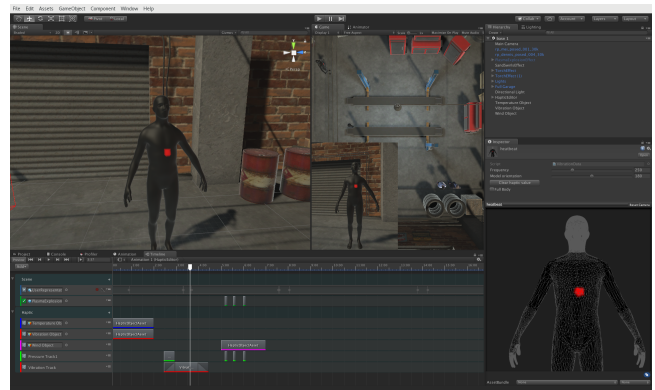
**Figure 2: Interface of the authoring tool. Based on the Unity®timeline system, haptic effects may be synchronized with other events and animations of the VR experience.**

**3.2.1 Egocentric effects.** Egocentric effects can be directly drawn onto the user (see Figure 3). To do so, the haptic designer paints on a perceptual model, depending on the target sensation. The spatial resolution of the effect is then defined by the density of vertices of the model. The parameters of the effect can be also tuned (frequency,

amplitude, intensity depending on the nature of the effect). The temporal aspect of the effect is then defined in the timeline.

Once edited, the designer adds a haptic track in the timeline. From there, the starting time and the duration of the effect is set. Fade in and fade out curves may be drawn (see Figure 2 - bottom right) to modulate the amplitude of the effect (values go from 0 to 1). Thus, various waveforms can be designed by playing with these parameters. Also adding multiple effects on one track at different locations on the user's body generate a moving pattern.

This type of effect is created from the asset menu and generate haptic asset file (vibration, pressure or temperature). These haptic files can be saved, modified and used in other projects, as listed in the design requirements.



**Figure 3: Design of an egocentric effect of vibration. The designer can directly select vertices to be stimulated and set the frequency of the stimulus.**

**3.2.2 Allocentric effects.** Allocentric effects are haptic effects that are defined in the user's space rather on the user's body. They can be seen as haptic objects that the user may touch. The haptic designer may then add these objects into the scene and define their shape and properties. Four effects may be added (temperature, vibration, pressure or wind). The wind effect is based on the pressure perceptual model. Extra parameters are available to change the shape (cuboid or sphere) or characteristics (temperature, frequency, wind force). These haptic objects are represented by their bounding box in the editor only. They are not meant to be visible within the VR experience although they can be parented to any visible object. For instance a regular sphere object, for which a spherical effect of vibration is associated, becomes touchable.

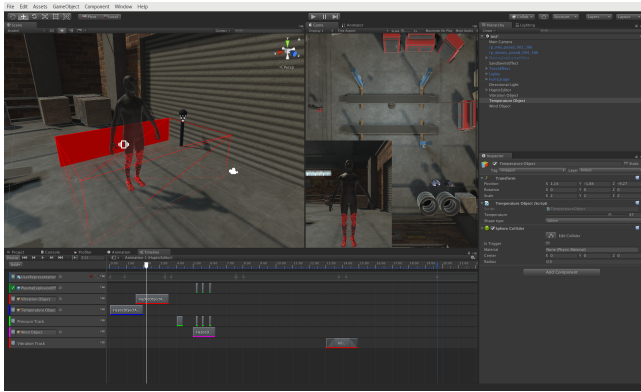
Once located in the scene, allocentric effects also have to be added to a custom track of the timeline. Haptic feedback is rendered when the user is located in the haptic object and when this one is activated in the timeline.

They are implemented as a new type of GameObject (i.e. object in the 3D scene, see Figure 4). Like any GameObject, they may be translated, rotated, scaled or animated, as listed in the requirements.

### 3.3 Haptic rendering

Once the VR experience starts, a Haptic Engine performs the haptic rendering on the available devices. The haptic perceptual models

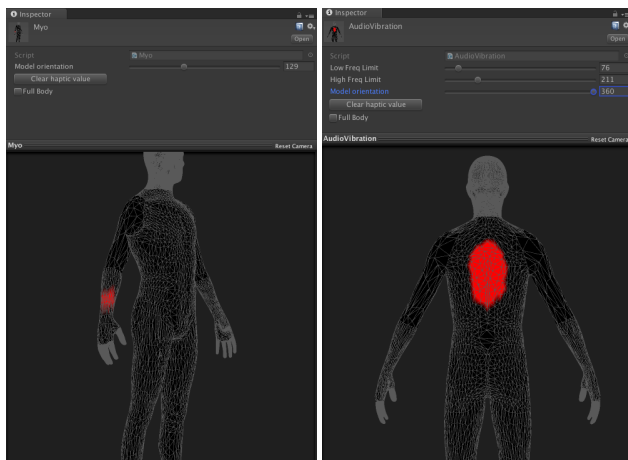




**Figure 4: Design of an allocentric effect.** A haptic object of vibration (red box) is located in the scene. It is felt when the user steps into it.

remain a central aspect of the rendering since the description of the device capabilities relies on them.

**3.3.1 Haptic devices configuration.** The configuration of a haptic device relies on a perceptual model (see Figure 5). Properties of a device (vibration, pressure, temperature, wind) and the simulated body parts are directly specified on the model (i.e. selected vertices). As listed in the requirements, many devices can be configured. For instance, a vibrating armband is configured by choosing the vibration perceptual model and selecting the vertices of the forearm (left or right depending on the user). In addition, max and min vibration frequencies of this device can be set.



**Figure 5: Configuration of haptic device.** Left - The Thalmic Myo is an EMG arm band that have vibration capabilities. Here it is configured to be worn on the user’s right forearm. Right - A vibrating backpack is defined.

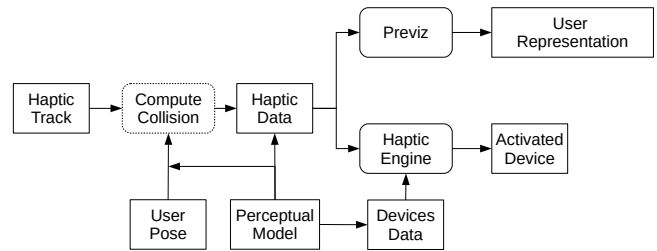
As a proof of concept, we implemented the rendering for several consumer devices (see Figure 6). Vibrations are provided by a Thalmic Myo (forearm), a Subpack M2 (back), the Oculus VR controllers (hands). Temperature and wind are delivered by a Dyson

Pure Cool Link. Although it is unlikely that a device configuration change, it can be edited. For instance a Myo can be worn on the left or right forearm. The configuration should adapted accordingly.



**Figure 6: User equipped with haptic devices: vibrating controllers, vibrating armband, vibrating backpack.** A fan providing wind and heat is also plugged in.

**3.3.2 Rendering workflow.** During the simulation, each haptic track of the timeline is processed according to the workflow depicted in Figure 7.



**Figure 7: Haptic Rendering workflow**

The perceptual models are at the center of the rendering workflow. In the case of an egocentric object, haptic data (i.e. the list of vertices defined by the designer) is directly provided to the haptic engine. In the case of an allocentric effect, the user’s pose is applied to the corresponding model and a collision detection is performed between this model and the haptic object. If there is a collision, the list of vertices inside the haptic object is computed. The collision detection is performed on the GPU by a compute shader to ensure a real-time simulation. The haptic data contain the list of vertices, and also include the type of the effect (vibration, temperature, wind, and pressure), the timestamp, and the parameters of the effect (frequency, amplitude, temperature, wind force). Two sub-systems use these data: a previsualization system and the haptic engine.

The Previz system colors the user’s avatar according to the designed haptic effects (see Figure 3 and Figure 4). It allows the designer to preview the rendering of the final haptic feedback. Vibrations are displayed in red, pressure in green and temperature in blue. The intensity of the effects changes the intensity of the colors. This feature mainly serves debugging purposes, colors are not meant

to be displayed to the actual end-user (i.e. not the haptic designer). Colors are combined in the case of multiple effects happening at the same time.

The Haptic Engine processes the haptic data for the haptic rendering. Having the configuration of each available device, its role is to distribute haptic data to the corresponding haptic devices. For instance if vibrations on the user's forearm should be rendered, it sends these data to all devices located on the user's forearm with vibration capabilities (the Myo for instance). If not, the effect is not rendered. To perform this distribution, the Haptic Engine compares the list of vertices of the haptic data to the vertices in the haptic device configuration files. Common vertices mean that the area can be stimulated.

The rendering itself is performed by a script associated to each device. Our architecture is generic since any device can be added. The script receives haptic data from a callback function providing the information needed for the rendering. If there is no device matching the type of effect, the effect is not rendered. It has to be noted that a device may render different types of effects. For instance, peltier cells can provide heat and coolness but also illusion of pain (thermal grill illusion), and vibrations can trigger illusion of movement of the limbs [24]. In general any effect can be mapped to any device, it is up to the device manufacturer to interpret the haptic data.

## 4 PILOT USER STUDY

We have conducted a pilot user study to evaluate the usability of our tool. The goal of this study was to identify design issues and to evaluate the performance of users in designing haptic effects. We have chosen to conduct a qualitative study to collect rich feedback on the interface, inspired from previous work [30] [31]. The authors asked participants to perform a temporal task (heartbeat pattern), a spatial task (indicating a direction to a car driver) or a context-based task (synchronizing a vibration to a visual animation). This evaluation was based on the grounded theory; i.e. interviews were conducted and patterns were identified from the results.

### 4.1 Evaluation protocol

We created a 3D scene in which we asked the participants to design four groups of effects (see Figure 8). The scene was a virtual garage in which a user was simulated, walking from point 1 to 4. Haptic effects had to be synchronized with these locations and the given timestamps.

The 3D scene was presented to the participants as well as a demonstration of the timeline and of our authoring tool (edition of egocentric and allocentric effects). Then we asked the participants to complete the four following tasks.

- T1 (Ambiance-based) From 00:00 to 02:00, the user is walking nearby a fire. Design a warm area ( $30^{\circ}\text{C}$ ) shaped as a sphere (radius 2m), with an additional vibration effects on the floor  $2\text{m}\times 2\text{m}$  ( $100\text{Hz}$ ).
- T2 (Spatial) The user is going to turn to the right. From 2:30 to 3:00, design a pressure effect shaped as a right arrow on her or his back to indicate the direction.
- T3 (Context-based) From 05:00 to 07:00 the user is walking in a windy area where three lightning strikes happen. Design a

wind effect ( $2\text{m}\times 2\text{m}\times 3\text{m}$ ), and synchronize a full body pressure effect to the lightning strikes.

- T4 (Temporal) The user is walking toward two people from 13:00 to 15:00. Design a heartbeat pattern on the torso (2 beat per second). Add a 0.5s fade in and 0.5s fade out to the effect.

Tasks were not randomized in order to evaluate the learnability of the tool. Participants were also free to take the time needed to complete the task. If they were lost, they were helped. The goal of this study was to identify the main design issues of the tool.

While performing the tasks we incited the participants to "think-aloud" and comment everything they were doing. After each task, we conducted a semi-structured interview to identify the participants' feeling of their performance and satisfaction with the tool. Even if we looked for qualitative data we also measured the effectiveness (completion of the task) and the efficiency (completion time) to get a comprehensive understanding of the usability.

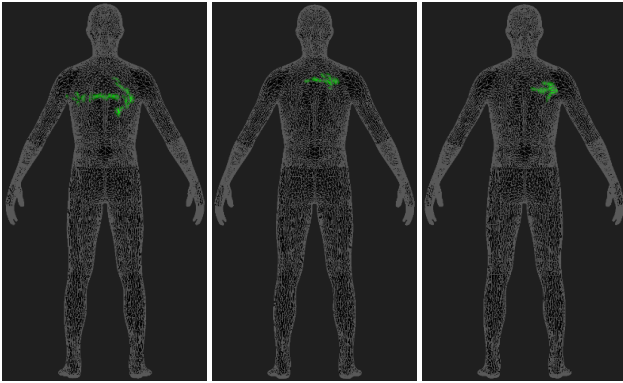


Figure 8: Top view of the 3D scene. Haptic effects had to be set at the four specified locations.

### 4.2 Results

We targeted Unity®experts and recruited eight male participants (age  $\bar{x} = 38.25$ ,  $\sigma = 10.79$ ,  $min = 21$ ,  $max = 54$ ). We asked them to evaluate their expertise from 0 (never used) to 5 (daily use):  $\bar{x} = 4.31$ ,  $\sigma = 0.80$ . We also asked for their expertise in timeline ( $\bar{x} = 0.25$ ,  $\sigma = 0.46$ ) and in haptics ( $\bar{x} = 1.12$ ,  $\sigma = 1.90$ ). The study lasted about 40 minutes.

All participants succeeded in the completion of the four tasks. For instance, Figure 9 shows the arrows drawn by three participants (task T2). Since we asked for artistic tasks, we only judged the overall appearance of the results. There was no strongly defined locations for allocentric effects or exact patterns for egocentric effects.



**Figure 9: Results of task 2 for P2, P3 and P4. Participants succeeded in drawing a right arrow on the user's back.**

Regarding the completion times, we noted an average of 330.75s ( $\sigma = 126.46$ ,  $min = 176$ ,  $max = 506$ ) for T1. T2 was 199.63s long ( $\sigma = 68.74$ ,  $min = 115$ ,  $max = 339$ ), 309s for T3 ( $\sigma = 84.80$ ,  $min = 234$ ,  $max = 450$ ), and 191s for T4 ( $\sigma = 80.87$ ,  $min = 110$ ,  $max = 344$ ). T1 and T3 are longer than T2 and T4 because two effects had to be created. Also, T1 is the longest task since it was the first one. Regarding these measures we observed that P3 (506s), P5 (497s) and P8 (405s) spent more time on T1 than other participants did. Otherwise completion times were similar. This let us think that the authoring metaphors make sense for a Unity® expert user.

The analysis of the observation and interviews of the participants led to four themes.

**4.2.1 Egocentric effects.** The egocentric approach was less obvious for the participants since there is no object to add to the scene hierarchy. Once the menu identified and the asset file created, the properties were however easily found in the Inspector window as usual. Interestingly P8 found this type of effect "quite intuitive".

However the addition of the effect to the timeline made sense as it is the only link between the effect and the scene. The difference with allocentric effect is that a track may contain different egocentric effects while an allocentric track is dedicated to one haptic object. Except for P4 and P7, all participants created two pressure tracks for T2 and T3.

**4.2.2 Allocentric effects.** The edition of allocentric effects was the more intuitive for the participants since they behave similarly to standard GameObjects. The creation, placement and re-scaling within the scene was not a difficulty at all. Specific properties were quickly found since they appear in the Inspector window similarly to other properties. P6 reported that it was "pretty obvious too use".

One drawback we observed was the fine placement of haptic object for some participants. Because they are represented by a wireframe always over other objects, their position is not always well perceived. These participants noticed the mislocation when the haptic effect was not depicted on the user representation during playback. Thus, they went back in edition mode to adjust the position again. This limitation is however due to the implementation in Unity®.

We also identified that the use of the timeline was not clear at first for allocentric object. Once defined in the scene, it was not straightforward for the participants to define a duration in the timeline since the effect is not supposed to be active when there is no collision.

**4.2.3 Interface control.** Overall, the tool was greatly appreciated (P3: "very intuitive tool", P5/P6: "nice tool", P7: "works pretty well"). Since it is deeply integrated in Unity®, participants were familiar with all the interaction techniques, even with a low expertise with the timeline system. P2 stated that the color on the user representation helped to figure out how the haptic feedback would feel like.

Two main points were criticized during the edition, especially for egocentric effects. First, the navigation window to rotate the camera around the perceptual model was slightly different from the one of the scene view. It was confusing for some users. Second, all participants reported that the painting tool on the perceptual model was too limited. So far only the vertex-by-vertex selection is possible which can be cumbersome for drawing complex patterns. Selection tools used in standard 3D modeler should be implemented.

**4.2.4 Design choices.** Finally, the results highlight different design strategies. To complete T3 participants were asked to design a full-body pressure effect on the user, synchronized to the lightning strikes. Most participants hesitated between an egocentric or an allocentric effect, especially P2 and P4, although they all ended up with an egocentric effect. Actually both methods can be used. The same vertices will be sent to the renderer (see Figure 7).

T4 was the design of a heart beat pattern, without strong indications. Most participants asked the question of using a vibration or a pressure pattern. Six of them used an allocentric vibration effect on the torso to generate a regular pulse of 2Hz. P3 and P8 chose a pressure pattern and precisely defined the pulse pattern on the timeline.

## 5 DISCUSSION

This first usability study shows that our authoring tool can be used to design haptic feedback. Actual haptic feedback was not evaluated here for two reasons. First, we wanted to evaluate the relevance of the colorization of the user representation to indicate haptic effects. Participants felt comfortable with this representation. Color feedback represented well the designed haptic sensations. Location and intensity were properly conveyed. Only the choice of color might be arguable. Secondly, haptic devices able to render an extremely fine haptic feedback on the whole user's body are hardly accessible. Nevertheless, thanks to the results of this study, the authoring tool will be improved and deeper user studies will be conducted. The iterative process of haptic authoring with actual haptic feedback will be especially evaluated.

We expect to integrate other devices. For instance, gloves based on microfluidic textiles could be a proper illustration of pressure effects, as well as the ultrasonic based device [1]. Force-feedback effects (and devices) will be also supported. Allocentric effect will naturally fit the current haptic algorithms (i.e. collision with



objects). This edition of egocentric effect will require more adaptation though. To support force-feedback devices, haptic data should also contain vertices position and velocity.

Another issue with the devices is the co-localisation of grounded devices and allocentric effects. For instance, we used a Dyson Pure Cool Link to perform effects of wind or of temperature. The device is placed in the actual user's space in a way to match its virtual position. But most of the VR applications allow teleportation to move over long distances in the virtual environment. The actual position of the device could be then obsolete. Teleporting systems must consider these constraints. More generally, more and various devices will be supported to identify the limitations of our system.

A central point of our approach is the use of the perceptual models to formalize the description of haptic feedback and haptic devices capabilities. The proposed models integrate findings from the literature to spatially encode haptic information. If the spatial acuity for pressure is well known, vibration and temperature perception are less documented. Psychological studies must be conducted to refine and validate the design of our models. For instance, perceptual thresholds for vibration depends on the stimulus frequency. HFX Studio could be of great help to design such experiments. In addition, the temporal aspect should be taken into account. For instance, in the case of thermal perception, temporal changes influence the spatial acuity [18]. The persistence of an effect should also be studied. Finally, other factors such as gender or age alter the haptic perception. A personalized adaptation to the end-user could be added. For instance, the model should fit the user's morphology.

The design of egocentric and allocentric effects may be improved. As described in the results, the selection of vertices on a perceptual model is basic. Designers expect a modern tool featuring many selection options. This will be implemented in future work. In addition to that, we will explore other "painting" methods. The edition on a 2D representation (i.e. textures) may be easier than on 3D models. Regarding the allocentric effects, the edition was reported as straightforward but only basic shapes are available (sphere and cuboid). A fine edition of the bounding box will be implemented. For instance, one would like to have an allocentric effect matching exactly the shape of another object. In this study we focused on unitary haptic effects. Yet an actual haptic sensation may combine several of these effects. For instance, the feeling of a hand on is a combination of pressure and temperature. Another functionality we would like to add is a list of high-level effects.

Our approach is currently implemented with the Unity® game engine, but it is not limited to it. Using the same perceptual models, different haptic editor could be created. They will produce the same data that could be easily decoded by any other haptic rendering application relying on the models. The goal of our approach is to create one content that can be rendered on any setup.

## 6 CONCLUSION

A new haptic editor based on haptic perceptual model was presented. It allows the edition of egocentric (user's space) or allocentric (world space) effects in a device agnostic way. So far, three models of vibration, pressure and temperature are proposed. The

rendering is then performed on any available devices, with their capabilities described with the perceptual models.

The editor was implemented in the Unity® game engine, with the support of several haptic devices. A pilot user study investigating the usability of the tool was conducted with height experts. Results showed that the edition of haptic feedback was easy and intuitive. Moreover it provided many inputs for enhancing the tool.

Future work will be dedicated to the improvement of the core features. Perceptual models manage the spatial encoding of the effect so far. The temporal aspect should also be taken into consideration. The number of effects will be extended to other types of haptic sensations (i.e. force feedback), more devices will be supported to validate the effectiveness of the models.

Numerous iterations are required to finely adjust the mapping between haptic sensations and haptic devices. But this tool is already usable for current VR productions with real-time content or omnidirectional videos. We believe that it will lead to new types of immersive haptic-audiovisual experiences.

## REFERENCES

- [1] Damien Ablart, Carlos Velasco, and Marianna Obrist. 2017. Integrating mid-air haptics into movie experiences. In *Proceedings of the 2017 ACM International Conference on Interactive Experiences for TV and Online Video*. ACM, 77–84. <https://doi.org/10.1145/3077548.3077551>
- [2] William S. Cain. 1973. Spatial Discrimination of Cutaneous Warmth. *The American Journal of Psychology* 86, 1 (1973), 169–181. <https://doi.org/10.2307/1421858>
- [3] Jongeun Cha, Yongwon Seo, Yeongmi Kim, and Jeha Ryu. 2007. An authoring/editing framework for haptic broadcasting: passive haptic interactions using MPEG-4 BIFS. In *Second Joint EuroHaptics Conference and Symposium on Haptic Interfaces for Virtual Environment and Teleoperator Systems (WHC'07)*. IEEE, 274–279. <https://doi.org/10.1109/WHC.2007.20>
- [4] Roger W Cholewiak. 1999. The Perception of Tactile Distance: Influences of Body Site, Space, and Time. *Perception* 28, 7 (1999), 851–875. <https://doi.org/10.1068/p2873>
- [5] Roger W. Cholewiak and Amy A. Collins. 2003. Vibrotactile localization on the arm: Effects of place, space, and age. *Perception & psychophysics* 65, 7 (2003), 1058–1077. <https://doi.org/10.3758/BF03194834>
- [6] D Cuartielles, A Göransson, T Olsson, and S Stenslie. 2012. Developing Visual Editors for High-Resolution Haptic Patterns. In *Workshop on Haptic and Audio Interface Design (HAID) – Posters and Demos*. 42–44. <https://mah.box.com/shared/static/r89ibgo0ovz9e1w4eretto30h120k19.pdf>
- [7] Fabien Danieau, Jérémie Bernon, Julien Fleureau, Philippe Guillotel, Nicolas Mollet, Marc Christie, and Anatole Lécuyer. 2013. H-Studio: An Authoring Tool for Adding Haptic and Motion Effects to Audiovisual Content. In *Proceedings of the adjunct publication of the 26th annual ACM symposium on User interface software and technology*. ACM, 83–84. <https://doi.org/10.1145/2508468.2514721>
- [8] Fabien Danieau, Anatole Lécuyer, Philippe Guillotel, Julien Fleureau, Nicolas Mollet, and Marc Christie. 2013. Enhancing Audiovisual Experience with Haptic Feedback: A Survey on HAV. *IEEE Transactions on Haptics* 6, 2 (2013), 193–205. <https://doi.org/10.1109/TOH.2012.70>
- [9] Fabien Danieau, Thomas Lopez, Nicolas Mollet, Bertrand Leroy, Olivier Dumas, and Jean-Francois Vial. 2017. Enabling embodiment and interaction in omnidirectional videos. In *International Conference on Multimedia and Expo (ICME)*. IEEE, 697–702. <https://doi.org/10.1109/ICME.2017.8019388>
- [10] Victor Adriel de Jesus Oliveira, Luciana Nedel, Anderson Maciel, and Luca Brayda. 2016. Spatial discrimination of vibrotactile stimuli around the head. In *Haptics Symposium (HAPTICS)*. IEEE. <https://doi.org/10.1109/HAPTICS.2016.7463147>
- [11] H. Dong, Y. Gao, H. A. Osman, and A. E. Saddik. 2015. Development of a Web-Based Haptic Authoring Tool for Multimedia Applications. In *IEEE International Symposium on Multimedia (ISM)*. 13–20. <https://doi.org/10.1109/ISM.2015.71>
- [12] Mohamad Eid, Sheldon Andrews, Atif Alamri, and Abdulmoteleb El Saddik. 2008. HAMLAT: A HAML-based authoring tool for haptic application development. *Haptics: Perception, Devices and Scenarios* (2008), 857–866. [https://doi.org/10.1007/978-3-540-69057-3\\_108](https://doi.org/10.1007/978-3-540-69057-3_108)
- [13] Mario J. Enriquez and Karon E. MacLean. 2003. The haptic editor: a tool in support of haptic communication research. In *11th Symposium on Haptic Interfaces for Virtual Environment and Teleoperator Systems, HAPTICS*. IEEE, 356–362. <https://doi.org/10.1109/HAPTIC.2003.1191310>
- [14] J. B. F. van Erp. 2005. Vibrotactile spatial acuity on the torso: effects of location and timing parameters. In *First Joint Eurohaptics Conference and Symposium on*

- Haptic Interfaces for Virtual Environment and Teleoperator Systems. World Haptics Conference.* 80–85. <https://doi.org/10.1109/WHC.2005.144>
- [15] Derek Gaw, Daniel Morris, and Kenneth Salisbury. 2006. Haptically annotated movies: reaching out and touching the silver screen. In *14th Symposium on Haptic Interfaces for Virtual Environment and Teleoperator Systems*. IEEE, 287–288. <https://doi.org/10.1109/HAPTIC.2006.1627106>
- [16] Martin Grunwald. 2008. *Human Haptic Perception: Basics and Applications*. Springer Science & Business Media. <https://doi.org/10.1007/978-3-7643-7612-3>
- [17] Da-Yuan Huang, Liwei Chan, Xiao-Feng Jian, Chiun-Yao Chang, Mu-Hsuan Chen, De-Nian Yang, Yi-Ping Hung, and Bing-Yu Chen. 2016. Vibroplay: Authoring Three-dimensional Spatial-temporal Tactile Effects with Direct Manipulation. In *SIGGRAPH ASIA 2016 Emerging Technologies*. ACM, 3:1–3:2. <https://doi.org/10.1145/2988240.2988250>
- [18] Lynette A. Jones and Michal Berris. 2002. The psychophysics of temperature perception and thermal-interface design. In *10th Symposium on Haptic Interfaces for Virtual Environment and Teleoperator Systems. HAPTICS*. IEEE, 137–142. <https://doi.org/10.1109/HAPTIC.2002.998951>
- [19] L. A. Jones and H. N. Ho. 2008. Warm or Cool, Large or Small? The Challenge of Thermal Displays. *IEEE Transactions on Haptics* 1, 1 (2008), 53–70. <https://doi.org/10.1109/TOH.2008.2>
- [20] Lynette A. Jones and Nadine B. Sarter. 2008. Tactile Displays: Guidance for Their Design and Application. *Human Factors: The Journal of the Human Factors and Ergonomics Society* 50, 1 (2008), 90–111. <https://doi.org/10.1518/001872008X250638>
- [21] Konstantina Kilteni, Raphaela Groten, and Mel Slater. 2012. The sense of embodiment in virtual reality. *Presence: Teleoperators and Virtual Environments* 21, 4 (2012), 373–387. [https://doi.org/10.1162/PRES\\_a\\_00124](https://doi.org/10.1162/PRES_a_00124)
- [22] Sang-Kyun Kim. 2013. Authoring multisensorial content. *Signal Processing: Image Communication* 28, 2 (2013), 162–167. <https://doi.org/10.1016/j.image.2012.10.011>
- [23] Yeongmi Kim, Jongeun Cha, Jeha Ryu, and Ian Oakley. 2010. A tactile glove design and authoring system for immersive multimedia. *IEEE MultiMedia* 17, 3 (2010). <https://doi.org/10.1109/MMUL.2010.5692181>
- [24] Susan J Lederman and Lynette A Jones. 2011. Tactile and haptic illusions. *IEEE Transactions on Haptics* 4, 4 (2011), 273–294. <https://doi.org/10.1109/TOH.2011.2>
- [25] Flavia Mancini, Armando Bauleo, Jonathan Cole, Fausta Lui, Carlo A. Porro, Patrick Haggard, and Gian Domenico Iannetti. 2014. Whole-body mapping of spatial acuity for pain and touch. *Annals of Neurology* 75, 6 (2014), 917–924. <https://doi.org/10.1002/ana.24179>
- [26] Sabrina Pančels, Margarita Anastassova, and Lucie Brunet. 2013. TactiPEd: Easy Prototyping of Tactile Patterns. In *Human-Computer Interaction – INTERACT 2013*. Vol. 8118. Springer Berlin Heidelberg, Berlin, Heidelberg, 228–245. [https://doi.org/10.1007/978-3-642-40480-1\\_15](https://doi.org/10.1007/978-3-642-40480-1_15)
- [27] Roshan Lalintha Peiris, Wei Peng, Zikun Chen, Liwei Chan, and Kouta Minamizawa. 2017. ThermoVR: Exploring Integrated Thermal Haptic Feedback with Head Mounted Displays. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems (CHI '17)*. ACM, New York, NY, USA, 5452–5456. <https://doi.org/10.1145/3025453.3025824>
- [28] William Rihn and Matt Tullis. 2017. Game Design with Haptics: Taking the Gaming Experience to the Next Level of Immersion. Unity Unite Talk, <https://www.immersion.com/events/unity-unite-austin/>.
- [29] Jonghyun Ryu and Seungmoon Choi. 2008. posVibEditor: Graphical authoring tool of vibrotactile patterns. In *International Workshop on Haptic Audio visual Environments and Games, HAVE*. IEEE, 120–125. <https://doi.org/10.1109/HAVE.2008.4685310>
- [30] Oliver S Schneider, Ali Israr, and Karon E MacLean. 2015. Tactile animation by direct manipulation of grid displays. In *Proceedings of the 28th Annual ACM Symposium on User Interface Software & Technology*. ACM, 21–30. <https://doi.org/10.1145/2807442.2807470>
- [31] Oliver S. Schneider and Karon E. MacLean. 2016. Studying design process and example use with Macaron, a web-based vibrotactile effect editor. In *Haptics Symposium (HAPTICS)*. IEEE, 52–58. <https://doi.org/10.1109/HAPTICS.2016.7463155>
- [32] William Steptoe, Anthony Steed, and Mel Slater. 2013. Human Tails: Ownership and Control of Extended Humanoid Avatars. *IEEE Transactions on Visualization and Computer Graphics* 19, 4 (2013), 583–590. <https://doi.org/10.1109/TVCG.2013.32>
- [33] Choo Kenneth K. Stevens, Joseph C. 1998. Temperature sensitivity of the body surface over the life span. *Somatosensory & motor research* 15, 1 (1998), 13–28. <https://doi.org/10.1080/08990229870925>
- [34] Unity®. 2018. Unity website. <https://unity3d.com>. [Online; accessed 01-October-2018].
- [35] Emanuel Vonach, Clemens Gatterer, and Hannes Kaufmann. 2017. VRRobot: Robot actuated props in an infinite virtual environment. In *Virtual Reality (VR)*. IEEE, 74–83. <https://doi.org/10.1109/VR.2017.7892233>
- [36] Markus Waltl, Benjamin Rainer, Christian Timmerer, and Hermann Hellwagner. 2012. A toolset for the authoring, simulation, and rendering of sensory experiences. In *Proceedings of the 20th ACM international conference on Multimedia*. ACM, 1469–1472. <http://dl.acm.org/citation.cfm?id=2396522>
- [37] Eric Whitmire, Hrvoje Benko, Christian Holz, Eyal Ofek, and Mike Sinclair. 2018. Haptic Revolver: Touch, Shear, Texture, and Shape Rendering on a Reconfigurable Virtual Reality Controller. In *CHI*. ACM. <https://doi.org/10.1145/2393347.2396522>
- [38] Zheng Zhang, Vinay Tannan, Jameson K. Holden, Robert G. Dennis, and Mark Tommerdahl. 2008. A quantitative method for determining spatial discriminative capacity. *BioMedical Engineering OnLine* 7 (2008), 12. <https://doi.org/10.1186/1475-925X-7-12>