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Not just seeing, but also feeling art: Mid-air haptic experiences integrated in a multisensory art exhibition

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ABSTRACT

The use of the senses of vision and audition as interactive means has dominated the field of Human-Computer Interaction (HCI) for decades, even though nature has provided us with many more senses for perceiving and interacting with the world around us. That said, it has become attractive for HCI researchers and designers to harness touch, taste, and smell in interactive tasks and experience design. In this paper, we present research and design insights gained throughout an interdisciplinary collaboration on a six-week multisensory display – Tate Sensorium – exhibited at the Tate Britain art gallery in London, UK. This is a unique and first time case study on how to design art experiences whilst considering all the senses (i.e., vision, sound, touch, smell, and taste), in particular touch, which we exploited by capitalizing on a novel haptic technology, namely, mid-air haptics. We first describe the overall set up of Tate Sensorium and then move on to describing in detail the design process of the mid-air haptic feedback and its integration with sound for the *Full Stop* painting by John Latham (1961). This was the first time that mid-air haptic technology was used in a museum context over a prolonged period of time and integrated with sound to enhance the experience of visual art. As part of an interdisciplinary team of curators, sensory designers, sound artists, we selected a total of three variations of the mid-air haptic experience (i.e., haptic patterns), which were alternated at dedicated times throughout the six-week exhibition. We collected questionnaire-based feedback from 2500 visitors and conducted 50 interviews to gain quantitative and qualitative insights on visitors' experiences and emotional reactions. Whilst the questionnaire results are generally very positive with only a small variation of the visitors' arousal ratings across the three tactile experiences designed for the *Full Stop* painting, the interview data shed light on the differences in the visitors' subjective experiences. Our findings suggest multisensory designers and art curators can ensure a balance between surprising experiences versus the possibility of free exploration for visitors. In addition, participants expressed that experiencing art with the combination of mid-air haptic and sound was immersive and provided an up-lifting experience of touching without touch. We are convinced that the insights gained from this large-scale and real-world field exploration of multisensory experience design exploiting a new and emerging technology provide a solid starting point for the HCI community, creative industries, and art curators to think beyond conventional art experiences. Specifically, our work demonstrates how novel mid-air technology can make art more emotionally engaging and stimulating, especially abstract art that is often open to interpretation.

1. Introduction

Humans are equipped with multiple senses to perceive and interact with their environment. However, in HCI, vision and hearing have been the dominant senses, and our sense of touch, taste, and smell have often been described as secondary, as the lower senses (Spence, 2011). HCI researchers and practitioners are however increasingly fascinated by the opportunities that touch, smell, and taste can offer to enrich HCI. Recent examples of such experiences include the novel olfactory display by Seah et al. (2014), taste-based gaming by Murer et al. (2013), olfactory in-car interaction by Dmitrenko et al. (2016), digital flavour experiences by Ranasinghe et al. (2014), and the added value of haptic feedback for audio-visual content by Maggioni et al. (2017). In particular, there has been a growing interest in uncovering the specificities of haptic experience design (Schneider et al., 2017) and the unique features of haptic

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stimulation that would allow the creation of emotionally engaging and meaningful experiences (Gatti et al., 2013; Seifi and MacLean, 2017).

With the advent of novel touchless technologies that enable the creation of tactile stimuli without physical contact (e.g., (Carter et al., 2013; Hamada et al., 2014; Hoshi et al., 2010; Long et al., 2014; Sodhi et al., 2013), a novel design space for tactile experiences has been opening up (Obrist et al., 2013). Most notably, it has been demonstrated that mid-air haptic stimulation can be used to convey emotions to the user (Obrist et al., 2015). This research has motivated further investigations of the design possibilities for creating novel mid-air haptics experiences (Ablart et al., 2017). Here we extend the use of mid-air haptics stimulation in the context of a museum, moving beyond a controlled laboratory environment to investigate the effect of multisensory stimulation on users' experience of art.

Museums and art galleries have always been in the forefront of integrating and stimulating multiple human senses, not only to explore new ways of representing arts, but also to increase the wider public interest in the artifacts being displayed. Harvey et al. (1998) showed that the use of touch specimens, sounds, and smells to complement the object along with interactive components (e.g., role playing induction device) and dynamic displays can have a strong influence on visitors' experiences, especially creating a strong sense of flow – being fully immersed and focused in a task (Csikszentmihalyi, 1997). Another intriguing work that relates to multisensory museum experiences is the Jorvik Viking Centre (Jorvik, 2017), where multisensory stimuli were used to enrich the experience of a tour concerning the Viking past of the city of York. This experience allowed visitors to touch historical objects (Viking Age artefacts), taste the unsalted, dried cod of the Viking diet, smell the aroma of the corresponding displayed objects, see the animals and inhabitants of the Viking city, and listen to the Viking sagas. More focused on the sense of touch, Loscos et al. (2004) presented how visitors could see and feel virtual 3D artworks (e.g., statues) using a haptic device that was connected to the user's right index finger to provide haptic feedback. This use of technology enabled users to touch and feel the contours and stiffness of the artwork.

Despite the increasing interest in the different senses as interaction modalities in HCI and related disciplines and professions (e.g., art curators, sensory designers), there is only a limited understanding of how to systematically design multisensory art experiences that are emotionally stimulating. Moreover, there also seems to be a lack of understanding on how to integrate different sensory stimuli in a meaningful way to enrich user experiences with technology (Velasco et al., 2016), including art pieces. Carbon (2017) replicated the work of Smith and Smith (2001) and pointed out the mismatches in the amount of time and space people spent in viewing artworks in a laboratory versus a museum context. Specifically, museum visitors had longer viewing time than was mostly realized in lab contexts, as well as longer viewing time when attending in groups of people. Additionally, this work uncovered a positive correlation between size of artwork and the viewing distance. These findings emphasize the fact that there is a need to carry out museum related investigations in the actual environment of a museum. Only through an in-situ approach, the intended users who have an intuitive interest and knowledge about art environments, are reached and can provide valuable feedback on the multisensory design and integration efforts.

Building on these prior works, in this paper, we present research and design efforts carried out as part of a six-week multisensory art display – Tate Sensorium – in an actual museum environment (i.e., Tate Britain art gallery). For the first time, mid-air haptic technology was used in a museum context to enhance the experience of a painting (i.e., the *Full Stop* by John Latham) through its integration with sound. The multisensory integration of touch and sound aimed to aid the communication of emotions and meaning hidden in the painting: *a large circular black spot in the approximate centre of an unprimed canvas* (see Fig. 2b).

In collaboration with a creative team of art curators and sensory designers, the specific experience for the *Full Stop* painting was created. A total of three variations of the experience were created, keeping the sound the same but changing the mid-air haptic pattern to investigate the effect of the sense of touch on the visitors' art experience (see illustrated in Fig. 6 and described in Section 3.3). We hypothesized that museum visitors would enjoy more experience involving the pattern specifically designed for Tate Sensorium (Tate pattern, the most sophisticated and purposeful designed experience), followed by the experience involving the Circle pattern (congruent with the visual appearance of the painting) and finally the Line pattern (incongruent with the visual appearance of the painting). Visitors' experiences were assessed through a short questionnaire at the end of the Tate Sensorium experience and through interviews to deepen our understanding on the subjective differences of sensory enhanced art experiences.

In the following sections, we first provide a review of related work on multisensory research and design in museums, followed by a general overview on the multisensory art display – Tate Sensorium in the Tate Britain art gallery. We include the description of the exhibited art pieces and sensory design space. We then focus on the work around the *Full Stop* painting and the design and development of the mid-air haptic patterns as part of the specific touch-sound integration. We provide a detailed description of the data collection process and the insights from the analysis of 2500 questionnaires and 50 interviews. We conclude with a discussion of our findings with respect to the lessons learnt, limitations and future opportunities for designing multisensory experiences outside the boundary of a laboratory environment.

2. Related work

Museums are public places that contain a collection of artifacts that hold values in artistic, historical, and cultural contexts (Alexander et al., 2008). Importantly, museums offer "a multi-layered journey that is proprioceptive, sensory, intellectual, aesthetic and social" (Levent and Pascual-Leone, 2014). Given the experiential aspect of museums, they (and exhibitors) have always been looking for new ways to diversify and enrich the experiences that they deliver to the visitors. Therefore, there have been examples and efforts of enhancing art objects through sensory stimuli to engage visitors and convey meaning.

2.1. Multisensory interaction in the museum

Museums are a forerunner in harnessing new ways of interacting with public users. Therefore, they are recognized within the field of HCI as relevant places for designing interactive systems to reach out to the public. An example is *Transcending Boundaries* (PACE, 2017), an exhibition that explored the transcend between physical and conceptual boundaries (e.g., elements from one work can fluidly interact with and influence elements of the other works exhibited in the same space) via visual, auditory, and tactile interactions. In addition, there are various cases in which the integration of multiple senses has been explored in museums. For example, Lai (2015) explored the "Universal Scent Blackbox", an artwork composed of boxes emitting five smells: grass, baby powder, whiskey tobacco, dark chocolate, and leather. Visitors to the installation could trigger an odour emission in another area for other visitors and vice-versa. This olfactory interaction attracted much interest from the visitors and became an inspirational probe for exploring olfactory interfaces for communication. Based on those prior explorations, it has been suggested that multisensory design in a museum may enhance the richness, and even the memorability, of the visitor's experience (Eardley et al., 2016; Lehmann and Murray, 2005), due to the emphasis on the multisensory nature of our everyday life experiences. Work by Teramoto et al. (2012) has shown that auditory and visual modalities mutually influence each other during motion processing of external events so that the brain obtains the best estimates of such events (Teramoto et al., 2012). Within HCI, we can additionally observe various efforts of integrating interactive technologies (e.g., touch screens,

multi-touch tabletop, see (Correia et al., 2010; Dijk et al., 2012; Hornecker, 2008; Ma et al., 2015) into a museum context to make artworks more accessible and enjoyable. In particular, Correia et al. (2010) used a multi-touch tabletop for multimedia interaction in museums, allowing visitors to access artworks' details and to assign tags to artworks.

Among the implementations of multisensory integration in museums, the integration of touch, together with vision and hearing, are the most frequent senses to be stimulated. For example, the Victoria and Albert Museum in London (VAM, 2017) provided visitors "touch objects" (e.g., a wise owl supervising the Sculpture Galleries and carved examples of different woods types) to experience the displayed artifacts. Visitors were also able to press a button next to an object to hear related audio descriptions. Another example is Ciolfi and Bannon (2002) who presented a sandbox used in an archaeology workshop to recreate an archaeological scene for the attending children to enjoy "playing the archaeologist". Harley et al. (2016) designed three interactive prototypes of prayer-nuts in an effort to convey and contextualize the historical, sensory, and its embodied information. These 3D printed tangible prototypes offered visitors sensory interactions of smell, touch, and sound with visual and audio feedback, which was relevant to the historical, social, and cultural context of the artifact. Loscos et al. (2004) created a virtual environment where visitors could see virtual 3D artworks (e.g., statues) and experienced an associated haptic feedback. A two-contact-point haptic device was linked to the right index finger of each visitor enabling them to touch and feel the contours and stiffness of the artworks through haptic feedback. However, the authors also pointed out that asking visitors to wear an exoskeleton, to enable the haptic feedback, is contradictory to the idea of free exploration in a museum. Thus, any devices designed for museum visitors should be as little invasive as possible.

From the artistic side, new technologies have been used as innovative means for creating art pieces. For example, Yoshida et al. (2004) created an interface for drawing using a stylus that provided different haptic feedbacks depending on the colours used to paint (e.g., participants experienced dark colours as heavy in weight and light colours as light in weight). In this work, the attachment of vibrotactile feedbacks to different colours created a novel experience for the creators of those digital/ media artworks. However, the authors did not investigate further the visitor's user experience once presented with these artworks. Another work explored the creation process of art integrating vision and touch (Azh et al., 2016). The authors ran one-on-one guided design sessions where visual artists created tactile design prototypes augmenting an existing work in their portfolio as a visual context. They analysed the creation following two rationales: (1) the tactile construct (a set of attributes that define its physical characteristics) and (2) the tactile intent (the variety of meaning assigned to a tactile feature). This analysis provides insights on how to design creativity tools for artists, but does not further investigate the museum visitors' experience.

The above examples show the interest and growing attention from various stakeholders in exploiting the human senses in the experience of artwork. In particular, the proliferation of haptic technologies creates a new space for experimentations for both researchers and artists alike. All prior work around the sense of touch is however so far limited to actual physical contact between visitors and the artifacts. Consequently, it does not yet exploit the use of novel contactless technology. This consequently raises the question of what user experiences around art can be created through the use and integration of mid-air haptic feedback in a museum context, in particular given recent evidence suggesting that mid-air haptic feedback can convey emotions (Obrist et al., 2015).

2.2. Haptics as an aid in communicating emotions

Recent developments of novel haptic technology, such as focused ultrasound (Carter et al., 2013; Hoshi et al., 2010), air vortex (Sodhi et al., 2013), and PinPad (Jung et al., 2017), aim to create new forms of tactile experiences. These works highlight the design opportunity of creating tactile sensations in mid-air, without requiring the user to physically touch an object, a surface or wear an attachment such as a glove or exoskeleton. Such experiences are of great interest when it comes to augmenting the experience of artworks, which are often fragile and would decay through multiple exposure to human touch. Yet, these new haptic technologies are intriguing to engage people with art emotionally, and to inspire artistic explorations and create memorable experiences.

Here we focus on communicating and mediating emotions through touch as a research area that allows the design of new emotion-related interactions (Obrist et al., 2015; Petreca et al., 2013). This is demonstrated in a recent work of Park et al. (2013) on the integration of touch during phone conversations in order to enhance emotional expressiveness in long-distance relationships. Moreover, there is a growing number of wearable systems that allow different types of social touch and an increasing number of studies demonstrating the rich expressiveness of tactile sensations derived from novel haptic systems (Hertenstein et al., 2009; Huisman and Frederiks, 2013; Jung et al., 2014; Le et al., 2014; Smith and MacLean, 2007; Wilson et al., 2016). Previous work has showed that participants used weak touches for positive emotions, and hard, fast, and continuous touches for negative emotions (Park et al., 2013). Others identified different types of touch for each emotion (e.g., stroking for love, squeezing for fear), but also reported participants' difficulty in differentiating the intensity of the expressions when applied through a wearable system on the forearm (Huisman and Frederiks, 2013). Altogether, these results promote the potential for communicating affective information through touch.

Most recently, this potential has been established for mid-air haptic technology using a haptic device that uses focused ultrasound to create one or multiple focal points on the human hand. A focal point is created using a fixed pressure (physical intensity) in mid-air using 40 kHz ultrasound waves and by applying the correct phase delays to an array of ultrasound transducers (Carter et al., 2013). This focal point of pressure can then be felt when modulating the ultrasound waves within the frequency range of the mechanoreceptors of the human hand (i.e., Meissner corpuscle and Pacinian corpuscle (Obrist et al., 2013). Using this mid-air haptic device, Obrist et al. (2015) created haptic emotional descriptions and identified a specific set of parameters (combining spatial, directional, and haptic characteristics) with respect to the two-dimensional emotion framework of valence and arousal. Based on this, the authors concluded that it is possible to communicate emotions through mid-air tactile stimulation in a non-arbitrary manner from one user to another. This work was a major inspiration for the team of practitioners, curators, and researchers working on the Tate Sensorium.

3. Tate Sensorium

Tate Sensorium was a six-weeks multisensory exhibition in Tate Britain, an internationally recognized art gallery in London, UK. In this section, we provide a general overview and background on the project, the overall ambition, and the specific aims for the multisensory augmentation of artwork through the use of mid-air haptic technology.

Tate Sensorium was the winning project of the 2015 Tate Britain IK Prize award that is specifically designed by Tate to support innovative installations using cutting-edge technologies that enable the public to discover, explore, and enjoy art in new ways. The ambition of Tate Sensorium was to enable museum visitors to experience art through all senses (vision, sound, touch, smell, and taste). This was achieved through the joint efforts of a cross-disciplinary team of collaborators from the art gallery, creative industries, sensory designers, and researchers (see details in the Acknowledgments). Flying Object (Object, 2017), a creative studio based in London, led the project and coordinated the activities across the various stakeholders.

Below we will first describe the setup of Tate Sensorium in the Tate Britain gallery (for an overview). We then provide the details on the artwork selection process and the design of the sensory stimuli for the finally selected art pieces (i.e., four paintings, see Fig. 2), their inte-

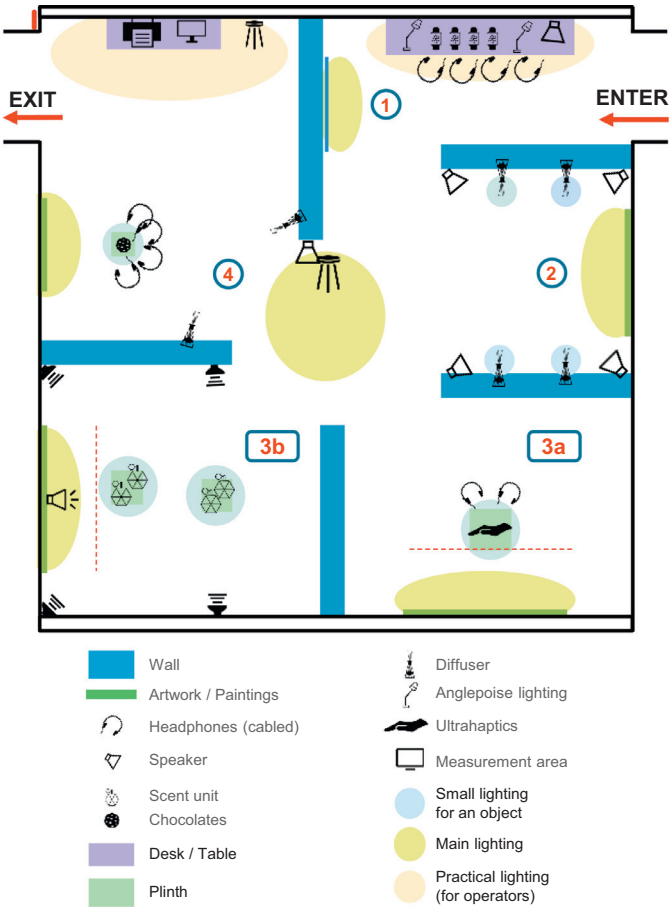

Fig. 1. Room setup of Tate Sensorium split into different sub-spaces (design by flying object): visitors enter on the right, where they receive the headphones (1). Then they move to the room (2) to see the first painting Interior II alongside olfactory and sound stimuli. After that, they move to either (3a) to experience the *Full Stop* painting alongside mid-air haptic and sound or (3b) to see the painting *In the Hold* through olfactory and sound stimuli. After swapping, visitors move to the last station (4) to experience taste sensations for the *Figure in a Landscape* painting.

gration and deployment in the museum, so that visitors were able to experience the different art pieces in a novel way. We will describe in even more detail the design of the haptic feedback using mid-air haptic technology and the scientific approach to collect user feedback (both led by the research team at the University of Sussex).

3.1. Overview on the setup in the museum

A large dedicated room inside the Tate Britain art gallery was used for Tate Sensorium. Fig. 1 shows the layout of the room divided into four areas specifying the final set up for the four selected paintings including details on the painting locations, lighting, senses used, etc. Each painting had a dedicated space and was hung on a wall in each section of the room (marked 2, 3a, 3b, 4).

Visitors first entered the room and were welcomed just inside the entrance (in front of the point marked 1 in Fig. 1). At that point, visitors put on headphones and listened to a welcome message, which briefly introduced the event and gave some general instructions. Visitors entered in a group of four at a time and viewed one painting at a time during the tour. After viewing the first painting, the group of four people split when reaching the second painting, so that two people continued with the second painting and the other two went to the third painting. These groups swapped afterwards, before moving forward all together to the fourth painting. The split was necessary due to the setup of the mid-air haptic technology for the second painting, which could only be used by two people at a time.

3.2. Artwork selection and sensory design

The selection of the artworks was a collaborative process between gallery professionals and external experts from different fields (at Flying Object, University of Sussex, and other independent sensory experts). At first, not only paintings but also sculptures were part of the pool of potential artworks. The list of potential artworks was compiled by Flying Object and included suggestions from the team at Tate Britain as well. This resulted in an initial pool of potential artworks consisting of 60 paintings. The selection criteria for the paintings focused on non-representational (or abstract) paintings, as it was agreed that they would leave more room for viewer interpretation. In other words, without any clear visual identity of objects within the painting, the non-visual stimuli would potentially have a stronger impact on how the artwork would be perceived. Additionally, the not-so-clear visual identity would give room for other sensory stimuli to guide the interpretation of the experience, given that sensory information can prime specific notions in users (Smeets and Dijksterhuis, 2014).

The availability of the artwork for the exhibition and the preparation phase (~2 months) was also a key criterion considered in the selection process. The final decision as to what artworks to select was made by the creative project team led by Flying Object, with sign-off by Tate Britain's management, in June 2015. Tate Britain's staff provided advice on the selection of artworks, based on their availability and suitability for inclusion (in terms of conservation, safety, and other artistic considerations). Further guidance on developing content (selecting appropriate interpretive/contextual information relating to each work) for the display, eventually translated into "sensory form" (e.g. audio material), was provided by Tate.

Four paintings were selected based on their potential for interpretation through different senses, as well as their availability at the museum for the duration of the display in August and September.

The four selected paintings were:

1. *Interior II* by Richard Hamilton[1]
2. *Full Stop* by John Latham[2]
3. *In the Hold* by David Bomberg[3]
4. *Figure in a Landscape* by Francis Bacon[4]

Fig. 2 shows the illustration shots of a participant experiencing the four selected paintings. Original copies of the paintings can be accessed via the Tate Britain website.[5] The details of each painting are in the next section alongside the description of the sensory stimuli.

The suitability of the sensory stimuli was decided by considering the literature on multisensory perception and experiences (by the university research team), suggestions from sensory professionals, and based on an iterative creative process. To do this, an on-site visit to the art gallery by the whole team was arranged. During the visit, the team experimented with the different senses in front of the artwork (e.g., using scented paper strips), as well as experiencing the mid-air haptic technology at the University with the project team.

The methodology for designing the sensory stimuli was as follows: (1) The team (of all people in the project) generated ideas for each of the four paintings selected, as well as a fifth reserved painting, prototyping them where possible (i.e. selecting actual scents or food ingredients, creating audio samples). (2) The team assigned a leading sense to each painting, along with a secondary sense (in the case of the painting *Figure in a Landscape* by Francis Bacon, a tertiary sense to accompany the

[1] http://www.tate.org.uk/art/artworks/hamilton-interior-ii-t00912.
[2] http://www.tate.org.uk/art/artworks/latham-full-stop-t11968.
[3] http://www.tate.org.uk/art/artworks/bomberg-in-the-hold-t00913.
[4] http://www.tate.org.uk/art/artworks/bacon-figure-in-a-landscape-n05941.
[5] http://www.tate.org.uk/visit/tate-britain.

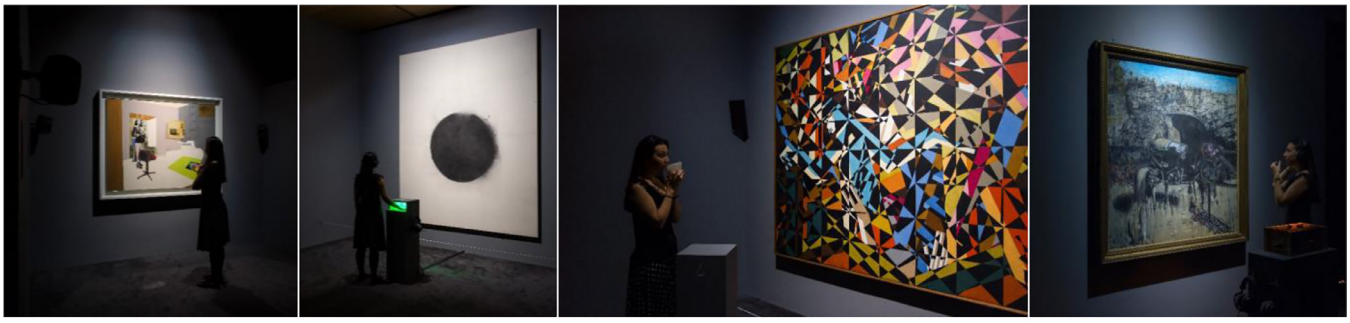

Fig. 2. Tate Sensorium exhibition at Tate Britain in 2015. (a) Installation shot of *Interior II* (1964) by Richard Hamilton. Photo: Tate. Illustration shows a participant experiencing the first painting, combining vision, audition, and smell. (b) Installation shot of *Full Stop* (1961) by John Latham © John Latham Estate. Photo: Tate. Illustration of a participant experiencing the second painting combining vision, auditory, and haptic (with the haptic pattern projected on the user's right hand). (c) Installation shot of *In the Hold* (c. 1913–4) by David Bomberg. Photo: Tate. Illustration of a user experiencing the third painting combining vision, auditory, and smell (by holding a 3D printed scent object close to her nose). (d) Installation shot of *Figure in a Landscape* (1945) by Francis Bacon. Photo: Tate. Illustration of a user experiencing the fourth painting combining vision, audition, and taste (by eating a piece of chocolate with multiple ingredients, namely, charcoal, sea salt, cacao nibs and smoky Lapsang Souchong tea).

taste). (3) The designers of each of those senses formed, with Flying Object, sub-teams to collaborate on the experience for each painting. (4) Through iterative discussions with experts and professionals between the teams, these sensory ideas were refined. Below, we present a detailed description of the "*Full Stop*", which was selected for the present study, where we utilized mid-air haptics to design the experience of such a painting.

3.3. Sensory design for the "Full Stop" painting

Here we provide details on the specific design for the second painting (*Full Stop* by John Latham), which was augmented through the integration of sound with mid-air haptic stimuli using the mid-air haptic device described by (Carter et al., 2013) and developed by UltraHaptics (2017a).

3.3.1. Background about the painting

The *Full Stop* painting by John Latham is an acrylic paint on canvas from 1961, with the size $3015 \times 2580 \times 40$ mm. It was presented in the room marked 3a in Fig. 1 and can be described thus:

"Full Stop is a monumental painting comprising a large circular black spot in the approximate centre of an unprimed canvas. The spot was created by repeated action with a spray gun, its curve delineated using weighted sheets of newspaper cut to the correct shape and, as a result, traces of rectangular forms are faintly visible outside the circumference. The circle's edges are blurred, particularly on the left side where a sprinkling of tiny and slightly larger dots emerge from the dense black of the large spot. The semi-mechanical process of making the spot, in which many dots are applied to the canvas at the same time, suggests the mechanical process of printing rather than the more traditional painting processes normally associated with a canvas. The painting's canvas is unstretched and is displayed pinned to the wall in the manner of a wall-hanging evoking signage and heraldry. The title, Full Stop, refers to text, and evokes the printed word. At the same time, the blurred edges of the spot and the slight halos around some of the larger dots at its circumference recall a solar eclipse, a black hole or the negative of photographs of light reflecting off planets in the dark galaxy".

(Quoted in Art after Physics, p.106.)

3.3.2. Sensory augmentation

Participants experienced this painting through the integration of sound and touch features. The sound was presented via headphones supplied by Polar Audio (manufactured by Beyer Dynamic) and which were worn by participants while in the room (see Fig. 3). The sound was created by a sound expert accentuating the interplay between the positive and negative space in the artwork, especially emphasizing the painting's duality of black and white. The audio was also designed to create

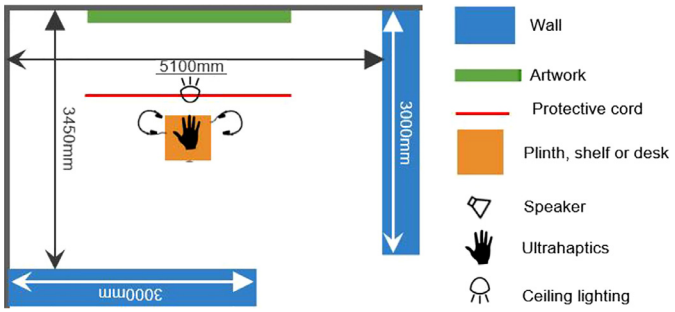

Fig. 3. Detailed setup of the space for the painting, *Full Stop* (left), with the specifications of the setup on the right.

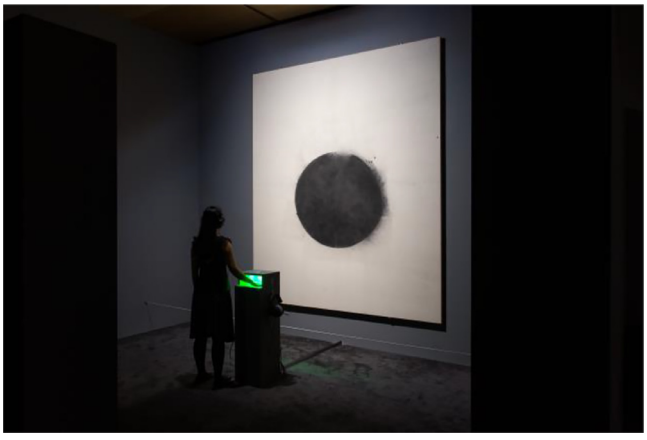

Fig. 4. Tate Sensorium exhibition at Tate Britain in 2015, installation shot of Full Stop (1961) by John Latham © John Latham Estate. Photo: Tate. Illustration of a participant experiencing the second painting combining vision, auditory, and haptic.

a sense of scale, of roundness and reference to Latham's use of spray paint, which was resembled in the mid-air haptic feedback.

Participants stood in front of a plinth box and put one hand, with the palm facing down, inside the top part of the plinth to have the haptic feedback delivered to their palm (see Fig. 4). The haptic device was placed inside the plinth, with the specifications shown in Fig. 5. A speaker gauze was placed 50 mm above the device to prevent participants touching the device. The haptic feedback was presented through the gauze when participants put their hand on top of it (Carter et al.,

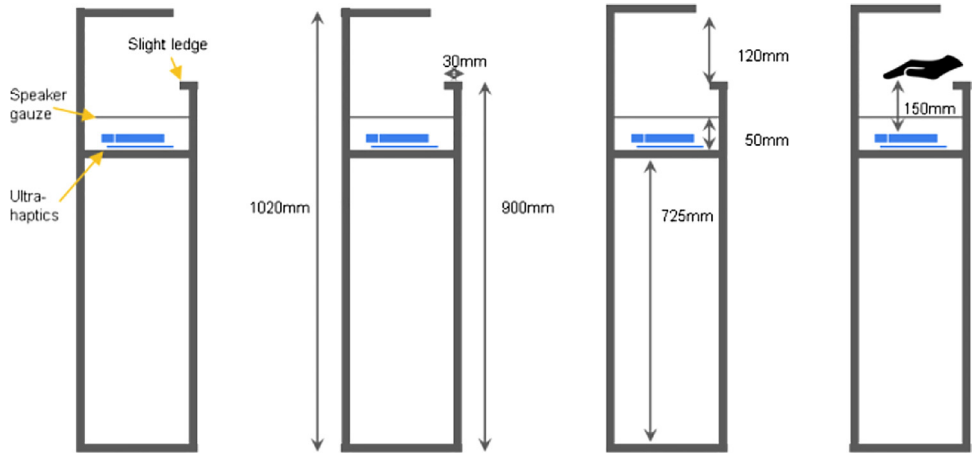

Fig. 5. The plinth created for the haptic stimulus for the Latham painting using mid-air haptic technology, the UltraHaptics device (design by flying object).

Fig. 6. Haptic patterns for the *Full Stop* painting. Main Tate Sensorium pattern (left), and two alternating haptic patterns (middle 'simple circle' and right 'line'). In the Main Tate Sensorium pattern, there is a circle shape composed of 16 points of varying size (having an increase/decrease in diameter of the formed circle), synchronized with the rain pattern.

2013). The height of the plinth was calculated so that it fitted comfortably with adults, children, and disabled visitors in wheelchairs.

3.3.3. Mid-air haptic pattern design

Synchronization between the sound and the mid-air haptic sensation was handled by self-developed software that could read Musical Instrument Digital Interface (MIDI) inputs (using RtMidi 2.1). Thus, the mid-air haptic patterns could be synchronized automatically with the sounds created by the sound designer. In other words, the sound designer could control the mid-air haptic patterns (frequency, intensity, and movement paths) to create a desired experience for the *Full Stop* painting. The final version of the sound file also synchronized with the desired mid-air haptic feedback sensation (as depicted in Fig. 6, left). This sensation had the "*Changeable circle sizes with rain drop sensations*" feature to enhance the visitor's experience of the painting. Specifically, it was created by a round-shape haptic sensation synchronized with the sound. The circle shape was composed of 16 points of varying size (having an increase/decrease in diameter), and was integrated with the rain pattern created by using one point at random positions on the whole hand.

Importantly, we further investigated the impact of the mid-air haptic stimulation on visitor's experiences. To do so, we created a set of seven alternative haptic experiences using three sources of inspiration: (1) the painting itself, trying to emphasize its visual properties (rounded), (2) contradicting the visual appearance of the painting (not rounded) and (3) emotional haptic stimuli based on the findings from Obrist et al. (2015). These seven patterns were:

- Pattern 1: A circle with no size variation.
- Pattern 2: A simple focal point in the middle of the palm.
- Pattern 3: One point moving from left to right.
- Pattern 4 & 5: Two points moving in a circle clockwise or counter-clockwise.
- Pattern 6 & 7: Two patterns designed based on the spatial and directional parameters identified by Obrist et al. (2015) to represent positive and negative emotions (positive: one point moving from the edge of the fingers to the wrist in a predictable way; negative: one point moving around 6 locations on the palm creating an unpredictable path).

Eight participants volunteered to evaluate these seven patterns alongside the main haptic pattern. Participants experienced each haptic pattern in a counterbalanced order, and then rated both the valence and arousal of each pattern on a Likert scale (1–9). Participants were also encouraged to describe what they felt and how meaningful they perceived the sensory integration for the *Full Stop* painting (which was represented by an A3 poster on the wall).

The results showed that "Circle" (pattern #4) and "Line" (pattern #3) patterns were the most distinctive ones for the *Full Stop* painting in terms of valance and arousal, accordingly. In specific, the Circle pattern had the highest valence ratings (6.43 ± 2.15) among all the patterns (averaged 5.02 ± 0.65) and an arousal average rating of 4.14 (± 2.48). The Line pattern had the highest arousal rating (5.86 ± 2.48) among all the patterns (averaged 5.11 ± 0.59) and a valence average rating of 5.71 (± 2.48). Notably, the Line pattern has a contradicting shape with the painting (showing a circle shape). Therefore, it was expected to have lower ratings in valence and liking as well during the science days. The two patterns chosen are described below:

- The "Alternative Circle" pattern had a circle shape but was only composed of 2 points instead of 16, rotating on a fixed position and of constant size (10 cm of diameter) on the palm.
- The "Alternative Line" pattern had a line shape and was composed of one point moving from left to right. When reaching the end of the line, the point started again from the left side and moved to the right to make the whole line (10 cm).

The three patterns (named Tate, Circle, and Line) were alternated during the Science days before closing the exhibition (see Fig. 7). In contrast, on the other days of the exhibition, only the Tate pattern was shown.

4. Procedure and method

In this section, we provide a detailed description of how the Tate Sensorium visitors experienced the multisensory installation and our method for capturing their experiences through questionnaires and interviews. Additionally, we explain the difference between Standard days

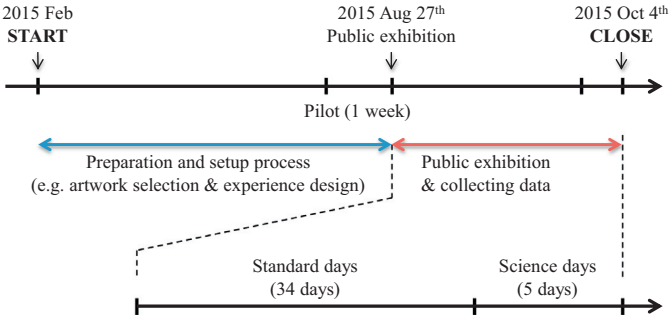

Fig. 7. Overview of the Tate Sensorium project timeline with a six-month preparation and design period, followed by a six-week (four weeks + two weeks extension) public exhibition and data collection period.

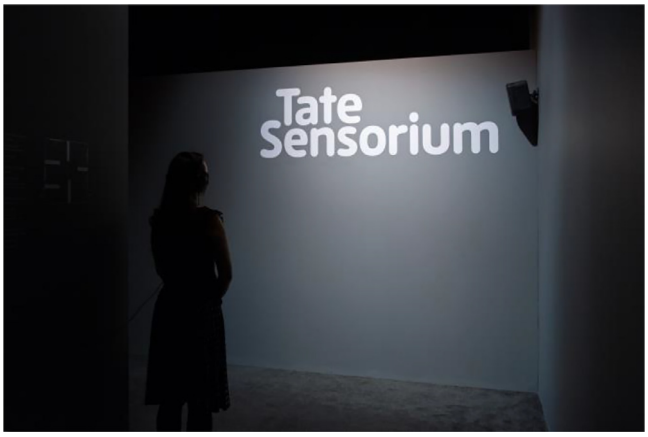

Fig. 8. Tate Sensorium exhibition at Tate Britain in 2015. Tate illustration shot of a participant's first stop point, after entering the room, where they hear a short introduction about Tate Sensorium.

and Science days (as depicted in Fig. 7). Overall, the exhibition opened to the public for 1 month and 8 days.

As mentioned before, the purpose of Science days was to investigate the impact of different parameters of mid-air haptic stimulation on visitors' experience. The three patterns were alternated at different times on each Science day (on the other days of the exhibition, only the Tate pattern was shown). Additionally, on Science days, we collected visitors' perceptions through questionnaires on the relative importance of each sense (vision, auditory, smell, touch, and taste) when experiencing the paintings at Tate Sensorium. On the final day of the display, visitors were also asked to take part in a short audio-recorded interview lasting for 10 minutes (see below).

4.1. Step-by-step procedure

Participants entered Tate Sensorium in groups of four. This group size was to allow Tate Sensorium visitors a truly immersive multisensory experience, as well as to separate visitors to attend different paintings in a smooth traffic. Another purpose was to mimic a common group visit to a museum. Moreover, a group of four people was a manageable group per session (15 min) allowing each participant to enjoy the artwork with the multisensory experience. After entering the main door, participants were welcomed and then guided by a member of staff until the end of the tour. First, participants stopped at the point marked 1 in Fig. 1. Here they were instructed to put on the headphones to hear a short introduction about Tate Sensorium (see Fig. 8), as follows:

In each room we want you to focus on the painting and let your senses do the rest.

Maybe the sensory stimuli will inspire thoughts, or memories. Maybe they'll suggest details in the paintings, or bring out shape or colour. Each of them has been made in response to the artworks, thinking about what they depict, and how and when they were made.

We want you to find your own interpretation of each artwork, and we hope these stimuli will help.

Additional audio guidance for each painting was provided, giving some details about the painting itself (by whom it was painted), and the accompanying multisensory stimulation (e.g., walk around the room to explore the different smells). Participants also received a wristband to capture their skin conductance response, which was used to create a personalized printout at the end of the tour. This data is not included in this paper as it was not the focus of the study led by the University team.

After the short introduction, participants removed their headphones and continued walking to the first painting (*Interior II* by Richard Hamilton, as marked 2 in Fig. 1). Here, they stood in front of the painting and were instructed (through the speakers in the room) to experience it as naturally as possible, and to move around the room to explore the three different scents (see Fig. 2a). Three minutes were given to all four participants to experience the painting. After that, participants were instructed by the staff to separate into two pairs of two participants to continue to the next painting.

Pair #1 went to the room marked 3a in Fig. 1 and view the *Full Stop* painting. Participants were asked to put on the headphones provided. Following the audio guidance, each participant was asked to put their hand into the empty space in the plinth to experience the mid-air haptic feedbacks (see Fig. 4 for an example and Fig. 5 for the plinth specifications). The mid-air haptic feedback was provided on the participant's palm, and was synchronized with the sound provided through the headphones. After the sound-haptic stimulus finished (1 minute), the second participant took a turn in experiencing the mid-air haptic stimulus for the *Full Stop* painting. Participants were instructed to enjoy viewing the painting while experiencing the sound and touch integration. The total duration given for participants to be in this room was 3 minutes.

Pair #2 went to the room marked 3b in Fig. 1 and viewed the *In the Hold* painting. There were two plinths in this room. On top of each plinth are two 3D printed scent objects. Participants were encouraged to experience the painting and the scents by picking up the scented object and smelling it (see Fig. 2c). Participants were given 3 minutes to explore the painting in association with the sound and smell stimuli in this room.

After, Pair #1 finished experiencing Room 3a, and Pair #2 went through room 3b, they switched roles. Pair #1 now moved on to room 3b and Pair #2 moved to room 3a, following the same procedure as described above for each of the two paintings.

Once both pairs completed Room 3a and 3b, all four participants moved to the final room (marked 4 in Fig. 1). Here, each participant put on the headphones again. They all stood in front of the *Figure in a Landscape* painting with a plinth in between. On top of the plinth was a box with 4 pieces of chocolate. Participants were encouraged to pick up a piece of chocolate and eat it (see Fig. 2d). Three minutes were given to participants to experience the painting and its associated taste and sound.

4.2. Methods used: questionnaire and interview

Once participants had finished visiting all four rooms, they were requested to move to the exit point. Just before exiting, participants were encouraged to complete a short questionnaire about their experience of Tate Sensorium. The questionnaire consisted of three questions for each painting: (1) visual liking (of the painting itself); (2) multisensory experience liking (the sensory stimuli integrated into the painting); and (3) emotional reaction (arousal) (see Fig. 9 for an illustration). These questions were used to quantify the added values of the designed sensory augmentation added to the experience of the paintings.

Participants answered using 5-point Likert scales (where 5 is the highest rating (Beeli et al., 2005). Participants were also asked to re-

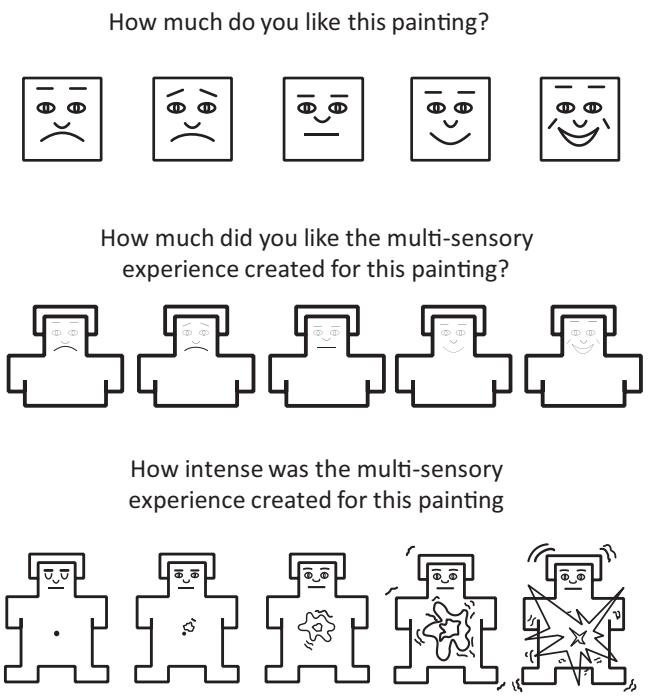

Fig. 9. Questionnaire about Visual Liking/ Multisensory Experience Liking / Arousal.

spond to some demographic questions (i.e., age, gender), and to report whether they would be interested in visiting such a multisensory experience again in the future (yes/no/maybe). This information was used in the analysis to explore differences between the experience ratings and users' personal backgrounds. Moreover, the curator of Tate Sensorium was interested in the age and gender distribution attracted by the multisensory display and if people would be interested in future events.

For the dedicated Science days, participants had an additional question on the importance of each individual sense (see Fig. 10). Participants signed a consent form before answering the questionnaires.

On the last day of the display, visitors of Tate Sensorium were also invited to take part in a short audio-recorded interview lasting about 10 minutes. The interviews aimed to explore: (i) the overall experience of the multisensory display, and (ii) gain specific insights on the experience created for the *Full Stop* painting, which integrated mid-air haptic feedback with sound. Here, we were particularly interested in understanding any qualitative differences in the perception of the three haptic patterns (the Tate Sensorium, Circle, and Line patterns as illustrated in Fig. 6), which were alternated between groups of participants.

An interview guide was defined based on those two main areas of interest and included the following eight questions for each interview session:

1. How would you describe your Tate Sensorium experience?
2. What do you think particularly about your experience of the *Full Stop* painting?
3. How would you describe the haptic experience you received on your hand?
4. How meaningful was it for you? Why?
5. How did the haptic experience match your perception of the painting?
6. What qualities of the painting were supported through the haptic experience?
7. Would you have expected something else, if at all?
8. Anything else you would like to share or say about the experience of this art installation?

In each interview session, between two and four users participated at a time. Each participant was encouraged to express her/his opinion one after another, as well as to react to each other's responses to allow some discussion and reflection on the multisensory experiences. This could help to obtain further insight about the visitor experiences in their own words.

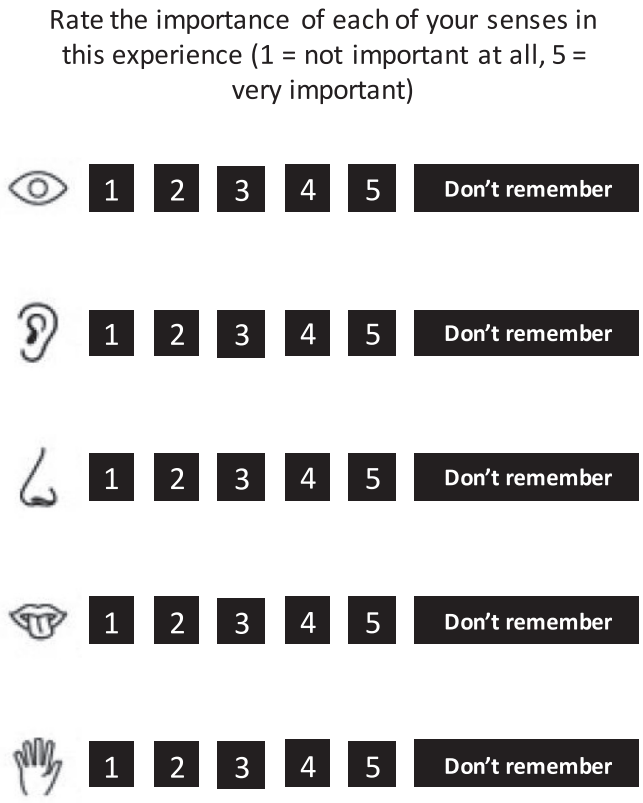

Fig. 10. Questionnaire about the importance of each individual sense.

Participants signed a consent form before taking part in the study, which was approved by the University of Sussex Science and Technology ethics committee.

5. Results

In total, we collected data from 2500 participants (1700 females, 800 males, mean age 36.00 SD 16.11). We analysed participants' visual liking, multisensory experience liking, and emotional reaction (arousal) ratings using a mixed effect design, ANOVA, where painting was considered a within-participants factor, and gender were considered between-participant factors. We used age to investigate how different age groups perceived the sensory augmentation of the paintings and to calculate correlations with the participant's ratings. We added 'haptic patterns' as between factor in the analysis in order to investigate any differences across the three haptic patterns used in relation to the participant's ratings.

Full interactions were considered in each ANOVA model we used. Overall, ANOVA's assumptions were tested on all the combinations of between and within factors. The Saphiro-Wilk test indicated the normal distribution of the data ($p > 0.05$ in all cases), Mauchly's test of sphericity was used to assess the sphericity of the data (again, $p > 0.05$ in all cases), and Levene's test the homogeneity of the data ($p > 0.05$ in all cases).

When ANOVAs showed significance, Bonferroni-corrected pairwise comparisons were performed. Moreover, given the high number of participants, Cohen's d was used on each significant comparison as an index of the effect size. Note that the effect size was not computed at the ANOVA level, given the fact that the power analysis of multiple way mixed effect experimental designs can lead to negative values and diffi-

Table 1
Selected paintings and their associated sense designs.

Paintings					
#1 *Interior II* by Richard Hamilton	√	√		√	
#2 *Full Stop* by John Latham	√	√	√		
#3 *In the Hold* by David Bomberg	√	√		√	
#4 *Figure in a Landscape* by Francis Bacon	√	√			√

Table 2
Overview on the results for the three mid-air haptic patterns created for the *Full Stop* painting, based on number of participants and ratings on visual liking, multisensory experience liking and experienced arousal.

	#1: Tate	#2: Circle	#3: Line
Number of participants	1889	133	152
Visual liking	3.99 ± 1.04	4.05 ± 1.03	3.97 ± 1.00
Multisensory experience liking	4.13 ± 0.97	4.14 ± 1.00	3.98 ± 0.99
Arousal	3.77 ± 1.04	3.90 ± 0.97	3.50 ± 1.13

cult interpretation, and it is still an active field of research (Roberts and Monaco, 2006).

In addition to the questionnaire data, we collected qualitative data from 50 participants through conducting interviews on the last day of the multisensory display. All the interviews were transcribed and analysed by one researcher (who conducted the interviews) based on the main areas of interest defined above (see Section 6).

Based on repeated readings of the transcripts and discussions in the group, we clustered the findings into three main themes, which we present in the following sections after the quantitative results gained from the questionnaire.

5.1. Effect of the different mid-air haptic patterns

With the aim of investigating the add-values of mid-air haptic in a museum context, we were particularly interested in evaluating the effect of mid-air haptic feedback on participants' experiences. For that purpose, three variations of haptic patterns were created for the *Full Stop* painting and alternated during the dedicated Science days (see Fig. 6 for illustrations of the haptic patterns). Table 1.

Table 2 summarizes the numbers of participants that experienced the different mid-air haptic patterns (Tate, Circle, and Line). Please note that the alternation between patterns was constraint to the dedicated Science days, hence there is a different number of participants experiencing each pattern.

The expectation was that participants would like the main pattern purposely designed for Tate most, followed by the Circle pattern, and the Line pattern being the least liked due to its incongruence with the visual appearance of the painting (rounded shape of the Full Stop on a large canvas).

To test this hypothesis (that is: whether the different patterns influenced the ratings of the participants), three multiple way ANOVAs were used to analyse the visual liking, multisensory experience liking, and arousal ratings, having as independent variables the age of the participants, the viewing order of the paintings, and the different haptic patterns into the model.

The analysis showed that the different mid-air haptic patterns only had an effect on the reported arousal ($F = 4.129$, $p < 0.01$). No statistically significant interaction was observed ($p > 0.05$ in all cases). Fig. 11 shows the averaged ratings for each pattern. Pairwise comparisons, using the Bonferroni correction, showed that pattern 1 and pattern 2 (Tate 3.77 ± 1.04 and Circle 3.90 ± 0.96) were found to be more arousing compared to pattern 3 (Line 3.50 ± 1.13, Cohen's d to the closest value = 0.38). These results are in line with our expectation of the Line pattern being the least appropriate sensation in mid-air as it does not resemble the rounded characteristic of the painting.

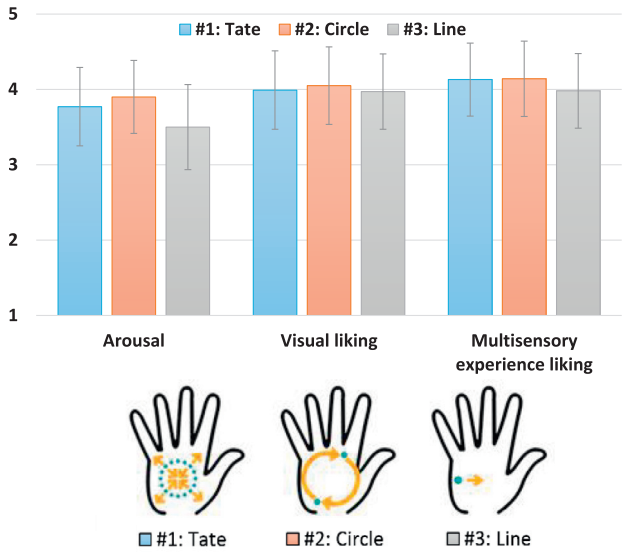

Fig. 11. (top) Ratings of arousal, visual liking, and multisensory experience liking for the different haptic patterns (with standard deviation, on a Likert scale of 1 to 5). (bottom) The schematic representation of the pattern on participant's hand: (1) Tate custom made; (2) circle; and (3) line.

Table 3
Summary of visitor ratings for each sense (with standard deviations) for the *Full Stop* painting (associated with mid-air haptic patterns).

	Sight	Sound	Touch	Scent	Taste
Mean	4.40	4.23	4.15	1.53	1.49
SD	0.91	1.03	1.15	0.96	0.95

5.2. Importance of haptic experience

Specific to the Science days (as described above and shown in Fig. 7), participants were asked one additional question designed to assess the perceived importance of each sense in each of the multisensory experiences (e.g., *Rate the importance of each of your senses in this experience*). This was inspired by previous work assessing the relative importance, to people, of the five senses in a given experience (Adank and Warell, 2006).

Table 3 and Fig. 12 show the average participants' ratings (with standard deviation) of the importance of haptic for the *Full Stop* painting. A repeated measure ANOVA and post-hoc pairwise comparisons with Bonferroni correction were used to assess which senses were considered more important for the painting.

We found that ratings of touch as rated significantly more important ($p < 0.001$) compared to the ratings of scent and taste. This is as expected for this painting as it was designed with the mid-air haptic (the sense of touch).

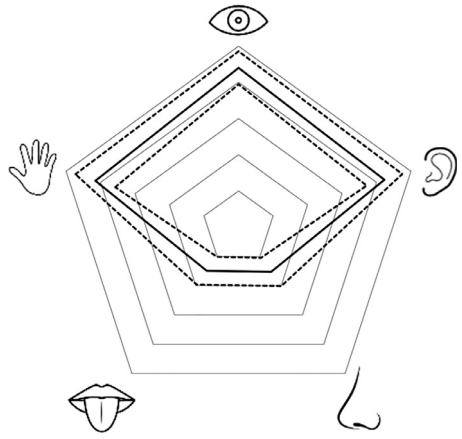

Fig. 12. The reported importance of haptic sense in the multisensory experience for the painting "Full Stop". Each sense is represented by a vertex of the pentagon, while each scale (from 1 - centre to 5 - vertex) are represented by the line and the points connecting the centre of the pentagon to the vertex. The solid black line represents the mean; the dotted lines represent standard deviation.

Multiple way ANOVAs were also conducted to assess any differences in gender, haptic patterns, on the relative importance of the different senses in their experience. No significant effect of any of these factors was found ($p > 0.05$ in all cases). That means that participants rated the added experiences of the associated sense similarly, regardless of their gender and haptic patterns.

6. Interview findings

As mentioned before, the aim of the interviews was to gain more insights into participants' overall experience of the multisensory installation, and more specifically to obtain qualitative feedback on their experience for the *Full Stop* painting. Below we summarise the main findings, further illustrated through quotes from participants (n = 50). We first present the qualitative findings of the overall experience of the multisensory exhibition (Section 6.1 and 6.2), followed by the findings that focus on the experiences of the *Full Stop* painting, with the mid-air haptic feedback (Section 6.3 and 6.4).

6.1. Overall multi-faceted experiences: immersive vs distracting

Participants described their experience of Tate Sensorium as "stimulating", "interesting", "mind blowing", "incredible, I really enjoyed it", "something new, unusual". While their feedback was overwhelmingly positive – which also fits the quantitative results – there were also some more critical voices. These critics were mainly based on different expectations, such as those expressed by some participants as *"I'd say it wasn't as strong as I thought it would be"*, and *"I expected something different, like something involving my whole body maybe, but I did like that I felt things very different in every painting."* Some participants literally expected a complete full body immersion in the painting through the stimulation of all senses. One participant was even ready to take off their shoes in expectation to be stimulated on the feet.

All participants strongly acknowledged that stimulating all the senses added another layer, dimension, and perspective to the experience of the paintings and thus opened new ways of thinking and interpreting art, in particular abstract art, which sometimes leaves people wondering how to interpret the work. One participant said: *"It helped create like a story for each painting because some of these paintings are quite abstract, so then with the sounds or the smells you kind of begin to start creating an idea of what's actually going on in the painting or what the story is."* The majority of participants stated that additional sensory stimuli did not change their initial liking of the artwork. However, some participants highlighted the potential of multisensory stimuli to turn their attention toward painting. *"It made me feel really different. The* Full Stop *and the reason I liked it is I would never be very impressed with an image like that normally but the sound, it was really awesome."* The interviews brought to the fore the general feeling that sensory augmentation can awaken a museum visitor's imagination, make the visit to the museum or art gallery more engaging, and has the ability to elicit strong reactions, establish a connection to, and build a narrative around the art.

The multisensory layers on top of the visual appearance of the paintings was described to allow stronger emotional reactions, such as empathy, being immersed, or even scared in front of the artwork. One participant described it as follows: *"In a way that gave the painting a narrative having that chocolate, you could build up a story like maybe you're walking on the field. […] and you could almost pull the mood from the sunshine as well."* For the *Full Stop* painting, the sensory experience was described as very intense due to the integration of mid-air haptics and sound. While one participant stated that *"I loved the sound of that one. It was kind of scary",* another participant focused on the sensation on the hand *"It was strange, it freaked me out because I wanted to pull my hand out* [from the plinth] *but I didn't want to because I wanted to carry on and see what it was like."*

In addition, participants highlighted the opportunity and danger of multisensory stimuli. For example, it could either *'help focus'* on the particularities of an artwork or *'distract'* from the artwork itself. Involving all the senses, when experiencing an artwork for the first time in such a setting could cause distraction, which was, however, not always described as negative distraction. Instead, it was sometimes a welcomed distraction, as the following statements represent: *"I liked the painting and I was kind of disturbed by the strong sound"* versus *"It's a funny thing but here the visual part was distracting. I was closing my eyes and trying to listen to the sound and touching and imagining because I had the painting in front of me even if I close my eyes."* For the *Full Stop* painting, one participant pointed to the positive emphasis of the haptic stimulus on the hand which made her notice the particularities of the artwork: *"I could kind of see it because of the spray, I noticed it at the start, I think on the right hand corner it looks like it's petering out a bit and it made me see that because I was imagining small droplets and I saw that whereas I hadn't seen it…* [without the feeling on the hand]*".*

6.2. Balance in sensory design: curated vs. explorative

The impact of the sensory stimuli on each individual's experience was not always straightforward and sometimes bipolar in the sense that multisensory augmentation of art can either open up opportunities for interpretation, but can also narrow down the visitor's perspective.

On the one hand, participants described the multisensory experience as supportive in understanding art, creating a story, elevating the visual experience through touch, taste, and smell and sound. While on the other hand, the experience was described as too prescriptive, orchestrated, and shepherded. One participant stated: *"I felt like it was leading you somewhere because it was already a choice, it was another choice from someone else, so I felt like I was being dragged into someone else's".* Another participant made the following statement: *"I think it was interesting to view the paintings in a different way but I think it was a little bit too conducted, especially the first one. You see this painting and you smell the smell and you know, it was too obvious in every one of them. The sound is matching perfectly the painting and the smell was matching perfectly the painting and the feeling of the hand was matching perfectly to little dots and the spray."* There seemed to emerge, although only from a handful of participants, a feeling of not being in control, and maybe not being able to follow their own exploration of the senses alongside the art, but then again being excited about the novelty of the engagement. This leaves space for other ways of designing future multisensory experiences and creating an interactive setting in a museum serving the varying expectations of visitors: being guided or allowing for surprise.

6.3. New mid-air sensation: feeling without touching

Overall, the *Full Stop* painting emerged as the most liked painting, not just from the questionnaire data, but also from the interview responses.

The combination of mid-air haptic (a new technology not yet available for the end user market) with sound was perceived as immersive and really opened up a new way of experiencing art. Participants described the multisensory experiences as follows: *"I'm speechless about that one. It made me goose bumpy"; "I loved it, I wanted to keep my hand in there. I loved feeling what the painting looks like and feeling the empty space and the negative space and then trying to relay that feeling onto the painting when I was looking at it."*

Participants also stressed the uplifting experience of touching without touch, just feeling air and variations of air patterns on the hand: *"I liked the touching thing, I found that particularly reactive"; "It was bizarre. It made me feel my body more, because I was actually touching something and it kind of like sent a pulse through me, which is cool",* and the associated uncertainty introduced through the new mid-air haptic technology: *"I suppose it was interesting with your hand in while watching the painting, and the not knowing, you can't see what's happening, so it was unknown what was coming. Whereas the smell, you knew there was a smell, it seemed less unpredictable."* The familiarity with a sensory stimulation and consequently the predictability of the experience was an interesting topic that emerged in the interviews and opens up the question for future investigations of its long-term impact.

Moreover, participants expressed the potential of this technology for artists themselves, providing them with a new opportunity to paint, create art, and provide people with new experiences.

6.4. Integration of touch and sound: three experiences

As explained above we were able to vary the mid-air haptic feedback for the *Full Stop* painting on dedicated Science Days, including the day we conducted the interviews. Thus, we were able to collect qualitative feedback on the experience for each of the three haptic patterns: Tate, Circle, and Line.

First, it is worth noting that the role of the sound in the combination of each of the three haptic patterns was described as very important. While the sound was dominant across all three haptic patterns, there was, however, a notable difference in the description of the experience between the three conditions. For the Line pattern, participants described the sound as very dominant, even more so than in the two other conditions. The Line pattern was perceived as less meaningful, as expected from our setup. The pattern was, moreover, described as distracting, random, and did not live up to the integration of a powerful painting and sound. Participants said: *"The sound really brought some of the pictures alive, the* Full Stop*, if I'd have walked through the gallery and looked at that, I would have just gone past it, whereas because I was there with the sound, I found myself looking at different parts of the picture."* Whereas others said: *"No, it didn't add anything, it was a distraction for me in that particular".*

In contrast, participants who experienced the Tate pattern described the experience as much more balanced between touch and sound. One participant said: *"I think the name* Full Stop *pretty much describes the painting, it is just a big black ball with white, but with like how the air is constant and then it stops, and then constant, stops, like it actually exemplifies the picture. It kind of makes sense."* The Tate pattern was well integrated with the sound and emphasized the physicality of the painting, thus creating an affordance for touch. The Circle pattern was still meeting the expectations of roundedness inherent in the visual appearance of the painting, but in contrast to the Tate pattern it introduced movement in the form of a clockwise rotation on the palm, though synchronized with the sound. Participants neither particularly liked nor disliked the pattern or the sound, but interestingly shared a lot of stories evoked through the sensation. One participant said: *"It's a very absorbing experience and really brought home that feel of the end of the world."* Another participant become agitated when talking about the sensation: *"I felt a bit like I don't know what's going to happen, is it going to grow bigger or smaller, is this going to explode."* It almost seemed that due to the slight deviation from a perfect design, participants were looking for explanations and coming up with their own narratives and short stories about the meaning of the experience.

6.5. Summary

Overall, all participants reported that they were looking forward to seeing more of this kind of multisensory installation in a museum in the future. Among the five senses stimulated, sound, and taste signals were described as the most intensively experienced. Taste was either described as scary, invasive to put something in your body, or comforting. The latter was however not often mentioned, as the stimulus itself (chocolate soil) was not as pleasant as usual chocolate but mixed amongst others with charcoal, sea salt and cacao as reference to the darkness of the painting (*Figure in a Landscape*). With respect to the three different haptic patterns for the *Full Stop* painting, it became clear that participants wished for more time and another try to fully grasp the experience conveyed with the novel mid-air haptic device. One participant said: *"If you ask me if I have the opportunity to go back to one of the rooms, I'd go to that one and try that thing again because it's addictive and just like feeling the whole body or something."* That suggests the need for further explorations into users' experiences over time.

7. Discussion

Tate Sensorium, a multisensory art exhibition, was designed to enable museum visitors to experience art through all their traditional senses: vision, hearing, touch, smell and taste. Overall, Tate Sensorium attracted over 4000 visitors over a six-week period, out of which 2500 gave feedback via questionnaires and a sub-set of 50 participants took part in a short interview, sharing their experience of the multisensory display. Our work presents the design and implementation of Tate Sensorium, with a specific focus on the use and integration of mid-air haptic stimulation as part of the experience of a painting. Below we discuss our findings and lessons learnt from this unique case study in particular from the perspective of exploiting a novel haptic technology beyond a controlled laboratory environment. We highlight opportunities and limitations for multisensory experience design when creating emotional engaging and stimulating art experiences.

7.1. Mid-air haptic design space to enhance art

Our results showed that different haptic patterns could selectively influence the reported degree of arousal of users. The original Tate pattern and the Circle pattern elicited significantly more arousal compared to the Line pattern. The higher arousal of these two patterns might be, as hypothesized, due to the geometric similarity between the *Full Stop* painting and the haptic patterns. In contrast, the Line pattern was described as "distracting" due to the confliction between what was being seen and what was being experienced through touch. This finding is in line with what (Gatti et al., 2013) previously reported for a lab setting, and extends their results for mid-air haptic stimulation (Obrist et al., 2015).

In addition, while the differences of liking between the three haptic patterns remained non-significant based on the questionnaire, the qualitative data suggests that the participant's subjective experience changed depending on the used pattern. The sound integrated with the haptic pattern became more important when the haptic pattern was not considered as meaningful in relation to the visual appearance of the painting (in the case of the Line pattern). That might indicate a specific case of sensory dominance of sound over touch (e.g. (Jousmaki and Hari, 1998), but also that minimal changes in the stimuli can change the meaning of

the conveyed experience. That was particularly interesting for the Circle pattern, which was rated in the middle of the liking scale (better than the Line pattern, but worse than the Tate pattern). Presented with the Circle pattern, participants seemed to be most stimulated in their imagination and expression of narratives. It is, however, an interesting question for further research to investigate what kind of paintings that mid-air haptics lends itself to (e.g., busier paintings with more details than the *Full Stop*).

Those insights into the subtle differences of haptic experiences and subjective perception of integrated sensory stimuli (i.e., sound and touch) can provide designers as well as curators and artists with a distinct opportunity to intentionally design for variation from the visual stimulus to create friction that leads to stronger engagement. This can be further facilitated through the development of new design creativity tools for artists by the HCI community (Shneiderman, 2007).

In addition, visitors of Tate Sensorium were asked about their experience of the multisensory experience of the artwork (with the question "*How much did you like the multi-sensory experience created for this painting*"). Our results show that high liking was elicited in all three mid-air haptic patterns for the *Full Stop* painting, with no significant difference between them. This might be due to the novel experience when visitors first encountered with mid-air haptic, designed for the artwork. Future investigation specifically to regular visitors might reveal the differences in more details between different mid-air patterns.

7.2. Design considerations for a multisensory art

By integrating mid-air haptic technology into a real-world environment, which has not been done before, the design team had to decide about the form of multisensory presentation that accounts for the experimental integration of this new technology in a museum context over an extensive period of time. From the visitor's feedback, we know that there was a high level of appreciation and liking for the multisensory experiences designed for the selected paintings. However, some visitors perceived Tate Sensorium as too pre-designed (choreographed) and somehow limiting the space for an individual journey (exploration). While this is an important point to keep in mind for future explorations, it is worth noting that it was a conscious decision by the project team to guide the museum visitor in a coherent and complete way through their experience of art enhanced through a new technology they have never experienced before (please note that this mid-air device was not available on the consumer market at that time). Alternative designs can be imagined, where the visitor is not even aware of the multisensory augmentation of an art piece and stays embedded in the natural flow of a museum visit. In conclusion, the insights gained from this research are clearly staged outside a controlled laboratory environment and still embedded in a semi-controlled set up in a dedicated area in the museum. That allowed us to collect relevant first hand experiences from the intended target users, just like suggested by recent work by Carbon (2017), who highlighted the fact that there is a need to carry out museum related investigations in the actual environment of a museum.

Based on those design decisions, relevant follow up research and design questions emerge, such as *whether the multisensory experience should become the piece of art in itself?; if multisensory stimuli should be a means to explore artworks according to the curator/artist's intention?*; and *if multisensory design should be simply used to facilitate individual exploration rather than be prescriptive?* These are only some questions that come to mind that require further explorations and are ultimately a balance between the advanced state of a technology, and the ambition and requirements of the involved stakeholders.

For Tate Sensorium, the purpose was clearly the augmentation of existing painting experiences via multisensory design. However, the interviews showed that there was an interest for exploration as well as for allowing artists themselves to create sensory experiences for their own artwork. This is in line with recent efforts described by (Azh et al., 2016), where visual artists created a tactile design prototype that augmented one of their existing works. A major challenge identified by the authors was the need to provide the artist with tools that allow them to express their imagination without reducing it due the technical limitations.

7.3. Opportunities for HCI research and design

Based on the involvement of curators, sensory designers, and creative businesses in this design and research project, it became clear to us that there is an immense need for tools and interfaces to facilitate the work and practices of sensory designers (e.g., sound designer). This consequently allow the meaningful exploitation of new technologies such as the mid-air haptic device used in this project. Such devices are often not easily accessible for designers or artists due to the requirements of specific programming skills (in our case C++). Although a collaboration across disciplines and areas, as demonstrated in this project, can overcome those technical challenges, it limits the creative exploration and exploitation of new technologies. Hence, it is great to see current developments around the latest version of the mid-air haptic device, that comes with a graphical user interface that allows designers and artists to freely explore different patterns and parameters (see Ultrahaptics (2017b) for their touch development kit). On top of this, there is still an enormous opportunity for the design of new interfaces and tools to support the engagement of artists and designers with technologies such as mid-air haptics.

As stated by Resnick et al. (2005) and emphasized by Shneiderman (2007), there is a need for these tools to be designed with "*low thresholds, high ceilings and wide walls*". In other words, the designed tools should be easy for novices to begin using them, yet provide ambitious functionalities to scale up for the expert user and their needs, and hence support a wide range of design opportunities. In our research, we aim to push solutions using multilayer interface design, which provide users with different ways of interacting with the tool (e.g., the user interface of the tool is adaptive to the user's skills using it). Some examples of this are video games, search engines (e.g., Google, Yahoo), and video editing tools (e.g., Adobe Premier) with various workspaces to accommodate the user's expertise. As mentioned before, Azh et al. (2016) analysed the creation of tactile feedback for visual arts and used the gained insights from this collaboration to guide the design of dedicated creativity tools for artists. Accordingly, tactile constructs and tactile intents define the "form" and "meaning" components of each tactile feature, respectively. Their findings indicate associations among the identified categories and between the two components, leading to design implications for expressive tactile interfaces. They also propose a user interface architecture, based on a design space for an expressive tactile augmentation design tool. This idea can be further extended and applied for other senses in the future.

7.4. Design trade-offs and limitations

Although this project revealed several insights into immediate reactions and reflections on the multisensory experience (overall very positive), it is certainly a challenge to draw on generalizations about the individual effect of the senses on the overall experience of art and its possible impact on art preference. Conducting research in a typically noisy real-world context that has several stakeholders involved makes it difficult to generalize. Nonetheless, the different lessons learned here might facilitate large-scale studies involving multiple sensory signals in highly ecological contexts.

Moreover, given the nature of Tate Sensorium, there is a limitation in terms of the amount of questions that we could include in the questionnaire, giving us only a snapshot of the users' experiences. In particular, we would have liked to expand on the questions related to the overall experience of the sound-touch integration for the *Full Stop* painting. This would help to understand better the influence of the augmentation of mid-air haptic on top of the visual appearance of the painting (akin to (Chion et al., 1994) who previously investigated the added value of

sound). Based on the interviews, we know, however, that participants usually used the visual characteristics of a painting to explain their experience with the other sensory stimuli.

Studying multisensory experiences outside a controlled laboratory environment comes with challenges and although our research took place in the field, it was controlled to a certain extent. Participants were guided through the different sections of the room but were still given freedom to experience the artwork (e.g., *Full Stop*) and the associated multisensory design (e.g., mid-air haptic feedback). Doing this ensures a valid background for comparing different conditions of mid-air haptic stimulation while providing participants the same experience as they normally have in a museum. Our results indicate that the use of technology should not limit visitor's freedom in exploring the space in the exhibition. This was reflected in their qualitative feedbacks and must be considered by designers in their follow-up installations. Yet, it is limiting a completely free exploration one can have in a museum environment. It is up to the researcher and stakeholder to find the right balance between design and research.

Furthermore, we did not explore the aesthetics and culture in museum as it is beyond our core expertise in HCI. Instead, we focused on exploiting the potential of novel haptic technology to create emotionally engaging and stimulating experiences in particular through its integration with other senses, in our case with sound. Nevertheless, it would be an interesting research topic for future investigation, from the perspective of aesthetic science, to study multisensory art appreciation (Chatterjee, 2013; Shimamura and Palmer, 2012).

Finally, the interviews revealed the need for more time to explore and experience this new type of experience. One of the two couples who visited Tate Sensorium twice said: *"I think compared to yesterday I tried to relate the sensory more to the picture because yesterday I didn't know what to expect so I was trying to look at how that works. Today I think I understand more, especially with the Full Stop with the air and the echo sounds, it made more sense with the picture."* This demonstrates huge potential for further exploration of experiences and engagement over time.

8. Conclusions and future work

Traditionally, museum attendees tend to experience art mostly through vision. Tate Sensorium allowed us to reflect on the process of enhancing art by considering all our major senses, particularly the sense of touch using novel mid-air haptics. The degree of success of this initiative depends on who one asks. From the point of view of the art gallery, the results of Tate Sensorium exceeded their initial expectations. The one-month exhibition was extended for two additional weeks given the massive interest from the public. From the creative team's point of view, it was also a success despite small technical problems with lightning and sound at the beginning. Overall, the whole installation ran smoothly and attracted media interest within the UK and worldwide such as the BBC (2017), the Wired (2015), and The Wall Street Journal (WSJ ,2017). From a research point of view, this project provided a unique opportunity to collect user data on multisensory art experiences and in particular on mid-air haptic experiences from a large user group. However, that opportunity also comes with practical constraints such as negotiating the integration of the data collection in the overall display design and timing, compromising the design of the haptic feedback and limited control over the artwork selection.

While the HCI research team contributed to the design and integration of the multisensory stimuli and materials, the final decision was mainly made by the creative team and curator of the art gallery. Balancing the different stakeholders' requirements and thoughts on the project could be challenging. However, at the same time, this environment encouraged the team to think beyond their traditional ways and methods of designing experiences and studying them. Museum visitors were not recruited for an experiment, but they came to enjoy art, new ways of experiencing paintings, and to engage their senses in a new exciting way. Therefore, the experience they received needed to be interesting and memorable.

Despite compromises (finding the right balance between the various stakeholder requirements) and potential limitations, we believe that our work allows a glimpse of how to create, conduct, and evaluate multisensory experiences in a museum. With projects such as Tate Sensorium, we are convinced that our understanding of multisensory signals in relation to art, experiences, and design, based on novel interactive technologies, can be advanced. In particular, we hope that this case study will inspire other researchers and professionals in the creative industry, to explore new ways of engaging people and exploiting all human senses in the design of new multisensory interactive experiences in the museum.

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