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Interaction with a large sized augmented string instrument intended for a public setting

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Interaktion med ett stort augmenterat stränginstrument avsedd för en offentlig miljö

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SAMMANFATTNING

Interaktiva installationer i offentliga miljöer har ökat i popularitet under det senaste decenniet, liksom även skapandet av digitala musikinstrument. I denna uppsats presenterar jag en studie av interaktionen med ett stort augmenterat stränginstrument avsedd för en stor installation i ett museum, med fokus på att uppmuntra kreativitet, lärande, och att ge engagerande användarupplevelser. I studien blev 9 deltagare videoinspelade samtidigt som de spelade med strängen på egen hand, följt av en intervju med fokus på deras upplevelse, kreativitet, och strängens funktionalitet Jag använde sedan McCarthy och Wrights ramverk för att analysera teknik som upplevelse och Frank E Williams kreativitets taxonomi för att analysera resultaten. I linje med tidigare forskning så betonar resultaten vikten av att designa för olika nivåer av engagemang (undersökande, experimenterande, utmaning). Dock så visar resultaten dessutom på att dessa nivåer måste ta hänsyn till användarnas ålder och musikaliska bakgrund då dessa starkt påverkar hur användaren spelar med och upplever strängen.

Interaction with a large sized augmented string instrument intended for a public setting

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ABSTRACT

Interactive installations in public settings have increased in popularity over the past decade, as well as the construction of digital musical instruments. In this paper I present a study of the interaction with a large sized augmented string instrument intended for a large installation in a museum, with focus on encouraging creativity, learning, and providing engaging user experiences. In the study, 9 participants were video recorded while playing with the string on their own, followed by an interview focusing on their experiences, creativity, and the functionality of the string. I then used McCarthy and Wright's framework for analysing technology as experience and Frank E Williams creativity taxonomy model to analyse the results. In line with previous research, results highlight the importance of designing for different levels of engagement (exploration, experimentation, challenge). However, results additionally show that these levels need to consider the users' age and musical background as these profoundly affect the way the user plays with and experiences the string.

Author Keywords

Interactive installations; museum exhibits; digital musical instruments; string instruments; sensor design; creativity; engagement;

INTRODUCTION

Interactive installations in public settings such as museums and art galleries have increased in popularity over the last decade as a way to encourage visitor engagement. Just to name a few examples, The Manchester Art Gallery created the "Clore Interactive Gallery" in the early 2000's, allowing visitors to explore real artworks using almost all of their senses, and the New York Hall of Science newly opened "Connected Worlds" exhibition lets visitors impact the environment of a fantastically animated world through their gestures and movements. Other museums have put their focus entirely on interactive installations, like the W5 Interactive Discovery Centre in Belfast that offers 250 different interactive exhibits for their visitors to explore.

With these types of installations, designers face new challenges having to consider the wide variety of possible users, the impact of the surrounding environment and the durability and reliability necessary for long-term (and sometimes unexpected) user interaction. It is therefore no surprise that several of these installations have been created by or in collaboration with different research institutes. Some examples are "The Well of Inventions" [32], an interactive mixed reality installation developed by PhD-students at the Royal Institute of Technology and the Museum of Science and Technology in Stockholm, and "Resonate" [18], a musical installation developed by master students from different design fields in Mainz and the ZKM museum in Karlsruhe. Evaluative research on museum exhibits has also been conducted, mainly with focus on engagement [1, 14, 16, 19], collaboration [14, 32, 33] and learning [1, 7, 14, 19, 29]. While the research about designing interactive museum installations has grown the past years, few articles have dealt with musical installations or have focused on how these installations can encourage creativity for the museums visitors.

In this paper, the study of a large sized augmented string instrument will be presented, with focus on how the participants interact with the string and how the interaction can encourage creativity and provide an engaging user experience. The study is part of a larger project for a future museum installation at the new Scenkonstmuseet[1] that opens in 2017, in Stockholm, Sweden. The project is a collaboration between the museum and the Multisensory Interaction Team at KTH, who together have developed the basic idea and the concept for the installation prior to this study. The final installation will consist of 5 similar strings in a dedicated room and will be called "Ljudskogen" (*Sound Forest)*. The string metaphor was chosen for the installation due to its affordances and familiarity, with the aim of making it as intuitive as possible [19]. For this particular installation, that means that anyone regardless of musical background should be able to play the instrument and be creative with it. The instrument, as presented here, acts as a formative prototype for the museum's future installation, and the study will, as previously mentioned, focus on the interaction with that instrument. The research question for this thesis is therefore the following:

How should a large size augmented string instrument be designed in order for the interaction to encourage creativity and provide an engaging user experience?

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[1] Performing Arts Museum: http://musikverket.se/scenkonstmuseet/

BACKGROUND AND THEORY

This section presents relevant background information for the study of this paper, *interactive installations in public settings* and *digital musical instruments*, and a theoretical framing of the concepts of *user experience* and *creativity*.

Interactive Installations in Public Settings

Much research has been done about interactive installations in public settings over the past decade, with particular interest in increasing engagement and learning. Several comprehensive studies have taken place at museums where many interactive exhibits have been evaluated and compared from these perspectives [1, 5, 7, 16, 19, 29]. A general conclusion among these studies is the importance of *layering* the activities and engagement. Both initial and prolonged engagement with an installation should be rewarded [19], but an early success experience for initial engagement is crucial as the first few seconds of interaction decides on whether a user continues to interact or turns to something else [16]. Complexity should then be increased for prolonged engagement with the exhibit, offering opportunities for exploration, experimentation and challenges [1]. Edmonds takes it one step further in his study [10] and discusses not only what creates initial and prolonged engagement (attributes that he refers to as "attractors" and "sustainers" respectively), but also what creates a growing relationship with the user that causes them to return to the exhibit on future occasions (attributes that he refers to as "relaters"). In an additional study by Edmonds, Bilda and Candy [5], they also noted that most users tend to leave the exhibit once they figure out how the system works, further supporting the idea of increased complexity for prolonged engagement.

Other studies have highlighted the challenges of designing for the broad target group that installations in public settings allow for. While kids and families form the main part of museum visitors [17], Taxen et al. [32] has noted that people take very different approaches to interact with these installations, and it is important to think how these multiple participation formats can be designed for when developing the exhibit. Some studies have also emphasized the importance of iteration and evaluation in all phases of exhibit development [18], as it is "irreducibly complex" [1]. According to them, the full complexity of an exhibit's interactive features can be seen only through the eyes of the visitors, no matter how experienced the designers are. A study by Campos et al. [7] also mentions the challenge that arises when an interactive installation is finally deployed, as many aspects are impossible to model or test by means of early prototypes (like the surrounding environments impact on the experience).

Digital Musical Instruments

Digital musical instruments (DMI) can be defined as any musical instrument that makes use of a computer for sound generation and in which the control interface is separable from the sound generator [25]. While DMI's has been a part of our society since the introduction of synthesizers in popular music in the early 60's, the research about such instruments did not really take off until the creation of annual conferences such as NIME (New Interfaces for Musical Expression) and SMC (Sound and Music Computing) in the early 2000's (the rapid increase in new DMI's since then has been documented in studies by Wanderley et al. [20, 24]). DMI's can be divided into three categories, *augmented instruments* (acoustic instruments to which additional sensors or controls have been added), *instrument-inspired controllers* (DMI's which are based on acoustic instruments) and *alternate instruments* (instruments which have no apparent origin in acoustic instruments) [25]. The instrument in this study falls under the category of *instrument-inspired controller*, but research regarding *augmented instruments* is also of interest and both will be presented below.

Within the field of augmented instruments, much work has been done on string instruments like guitars, violins and pianos [4, 11–13, 22, 23, 27, 35] with particular interest in sensing gestures or position of a player's fingers on the instrument. Most previous approaches to this have been based on image analysis, as noted by Guaus et al. [13] who in their study instead proposed a method of capacitive sensing. While this method successfully managed to capture gestures and touch, as shown in similar studies by McPherson et al. [23] and Tobise and Takegawa [35], it has been less successful for position measuring due to body impedance causing too much interference with the system [4]. In another study by McPherson et al. [22], optic sensors were used to accurately measure the height position of a pressed key on a piano, while Newton and Marshall [27] has used infrared sensors to detect strumming motions on an augmented guitar. Infrared sensors were also used in a conducting baton for the musical exhibit "Personal Orchestra" at the "Haus der Musik" in Vienna [6]. The baton enabled users to control the tempo, dynamics and instrumental emphasis of a pre-recorded orchestra through natural conducting gestures.

An interesting instrument-inspired controller that bares some resemblance to this project is by Knichel et al. [18], who created a stringed, interactive and collaborative musical room called "Resonate". In "Resonate", eight oval objects were distributed on the floor with elastic cords attached from metal rings in the ceiling. Piezo sensors were attached to the metal rings to sense vibrations from the cords, which then triggered an individual sound for each of the objects, creating an "atmospheric composition". Another ambitious project was the "Brain Opera", a touring interactive, multimedia opera [29]. In the operas first act, audience members were presented to the interactive "Mind-Forest", an exhibition area consisting of 29 different, human-scaled, furniture-like, DMIs. The sensing technologies utilized in the instruments included, among others, force, capacitive and infrared sensors. This allowed for audience members to participate and create personal music that were later incorporated in the professional performance for the operas second act.

User Experience

"User experience" can be a somewhat vague term and several researchers have discussed its meaning throughout the years. Don Norman has been credited with inventing the term back in 1995 [28], defining it as *"User experience encompasses all aspects of the end-user's interaction with the company, its services, and its products."*. The definition is quite broad but is viewed from the perspective of a company. Norman has since then expanded on his definition, breaking down experience into visceral, behavioural and reflective levels, and as the definition of "user experience" is still evolving, so is the framework for analysing it. Examples can be found in Peter Morville's "honeycomb diagram", illustrating each facet of user experience, or Stephen P Anderson's "hierarchy pyramid of user needs" [2]. While these models are helpful tools for user experience design, they are, like most models within the field, mainly focused on websites and mobile applications. Due to the aesthetic nature of the final installation for this project, being a musical instrument in the setting of a museum of performing arts, it is relevant to look elsewhere for analytical user experience tools.

In his book *Art as Experience* [9], pragmatic philosopher John Dewey talks about experience as constant and something that occurs continually, as we are always in the process of living, but also discusses the definition of an "aesthetic experience". While the term has usually been reserved for experiences in the world of the arts, Dewey means that every prosaic experience can be of aesthetic quality, as all experience can be rich and fulfilling. In order to analyse the quality of such experience however, Dewey identified the processes of culmination, conservation, tension and anticipation to refer to the internal dynamics of experience. Building on Dewey's pragmatic approach to experience, Wright and McCarthy provide a framework for analysing technology as experience in their book *Technology As Experience* [21]. The framework consists of four intertwined "threads of experience" and is accompanied by six non-linear sense-making processes. While the four threads outline the compositional, emotional, sensual and spatio-temporal elements of an experience, the sense-making processes (*anticipating, connecting, interpreting, reflecting, appropriating, recounting*) are of more interest to this study as they dwell deeper into the personal traits of the user during an experience and are therefore more evaluable from a user perspective. *Anticipating* refers to the expectations, possibilities and ways of making sense that we bring prior to the event of the experience. *Connecting* refers to the immediate, pre-conceptual and pre-linguistic sense or feeling of a situation encountered. *Interpreting* refers to the discerning of the narrative structure and possibilities of the unfolding experience, what has happened and what is likely to happen. *Reflecting* refers to the judgments made about the experience as it unfolds, which happens at the same time as interpreting. *Appropriating* refers to relating the experience to our own sense of self, in context to our personal history and future. *Recounting* refers to telling the experience to others or ourselves, which gives us the opportunity to find new possibilities and meanings in it.

Creativity

Creativity is a big part of experience, both in the views of philosophers and researchers. Apart from Dewey, pragmatic philosopher Mikhail Bakhtin also inspired Wright and McCarthy's work in *Technology as Experience*. Bakhtin believed "*that to live is to create*", and that the act we describe as *creative* is just extensions of the sorts of activity we perform all the time [26], which can be reflected in Wright and McCarthy's views that "*in an open world, all action is creative, a fresh use of intelligence producing something surprising and new every time*" [21]. So while all action can be defined as creative, it complicates the evaluation of an act from such a perspective. According to psychologist Robert Sternberg, most investigators within the scientific field would agree on the general definition of creativity as *"the process of producing something that is both original and worthwhile"* [31], but what is "worthwhile" is a highly subjective notion and again therefore complicates evaluation. Within psychology however, the act of *divergent thinking* (exploring many possible solutions to a set problem) is often seen as correlated with creativity (as opposed to *convergent thinking*, where one focuses on coming up with a single, "most correct" answer to a set problem), and has been used as a measure of creativity by educational psychologist Frank E Williams. Drawing from the foundations of divergent thinking, he created a model of eight different creative skills that was used to learn and measure creativity among students, called *Williams Taxonomy* [36]. The skills were *fluency* (the ability to generate many ideas so that there is an increase of possible solutions), *flexibility* (the ability to produce different categories of ideas), *elaboration* (the ability to add on an idea), *originality* (the ability to create unique ideas), *complexity* (the ability to conceptualize multifaceted ideas), *risk-taking* (the willingness to be daring and try new things), *imagination* (the ability to dream up new ideas) and *curiosity* (the trait of exhibiting probing behaviours, asking, searching and wanting to know more about something).

METHOD

The prototype was developed through an iterative design process and was continuously evaluated by members of the research group before the actual user test took place (for further details on the prototype, see the next section).

The study aims to evaluate the interaction with the prototype and user tests were conducted during a one-week period with 9 participants (see Table 1). The participants represented different parts of the museums envisioned target group of children, parents and young adults with musical interest. Three children in the ages of 9-11, four young adults in the ages of 23-29 and two parents, both 53 years old, participated in the user tests. The children were all male, while half of the young adults and parents were female and male respectively.

The setup of the user tests was as follows: First, a brief interview was held to gather information about the participant's experience of music and museums. Then, the participant was left alone with the string in a lab room. No prior explanation of how the string worked was given to the users, only that it would be a part of a larger music installation at Scenkonstmuseet. Instead they were free to play around and explore the strings capabilities and limitations for as long as they felt like. To increase the probability of capturing their thoughts and considerations in action they were encouraged to think aloud during the interaction with the string. Lastly, semi-structured interviews were conducted in three parts. The first part dealt with the different processes of the users experience (*anticipating, connecting, interpreting, reflecting, appropriating and recounting)*, based on the framework provided by Wright and McCarthy [21]. The second part dealt with the creative skills displayed by the users (*fluency, flexibility, elaboration, originality, complexity, risk-taking, imagination and curiosity)* during interaction, based on the model on creativity provided by Frank E. Williams [36]. The last part focused on the functionalities of the string prototype and its material. The questions were first designed for adults and then reformulated with easier terms for the children (for example, the question "Did you feel like you could create something *original?*" was changed to "Did you feel like you could create something *new?*").

The participants' interaction with the string and the interviews were recorded using a video camera. The interviews were then thematically analysed for common, reoccurring themes. These themes where then used when returning to the filmed video footage for further analysis of what actually seemed to occur during the interaction, with focus on the processes of the users experience and the creative skills displayed.

User	Age	Gender	Musical Background
C1	9	Male	No previous experience
C2	10	Male	Guitar, one semester
C3	11	Male	No previous experience
Y4	23	Male	Drums, 4 years when younger
Y5	24	Female	Piano, 4 years when younger
Y6	27	Male	Piano, 9 years
Y7	28	Female	Piano and violin, 21 years
P8	53	Male	No previous experience
P9	53	Female	Piano and guitar, 4 years when younger

Table 1. Participants for the user tests.

THE AUGMENTED STRING PROTOTYPE

The augmented string instrument prototype consisted of a plastic, 14mm thick, optic fiber cable that was fastened to a wooden structure (see Figure 1). An Arduino UNO microcontroller was connected to an analogue 3-axis accelerometer (ADXL335) for measuring string displacement, placed on the top of the cable, and to an ultrasonic rangefinder (LV-EZ4) for controlling pitch, placed next to the cable on the wooden structure, facing the floor. A 20mm piezo element (7BB-20-6) connected to an audio card was also placed on the top of the cable (see Figure 2) to detect attack and velocity. Pure Data was used to process and create audible sounds based on the incoming sensor data from the Arduino and the piezo element.

By striking or pulling and then releasing the string with a force above a certain threshold, the piezo element detects an "attack" on the string, which in turn tells the system to trigger a note. The note's volume, attack and release depend on the force registered by the piezo element at the moment of the onset, and the note sustains until the string has stopped vibrating for about 300 ms. Muting a triggered note by holding the string has the same 300 ms delay. Sound can also be triggered without the piezo element detecting an attack. The accelerometer senses changes in velocity along its axes due to slight displacement of the string by either touching or shaking the string. This causes the system to slowly fade in the previously played note with a volume depending on the level of the velocity. Keeping the velocity above a certain threshold (by for example continuously shaking or pulling the string) without triggering an attack on the piezo activates a wah-wah filter that increases in intensity the longer the velocity is above that threshold. If the piezo notices an attack during these motions the wah-wah filter is turned off.

At the moment of the attack, the ultrasonic sensor registers the distance from the top of the string to the hand (or other body parts closer to the sensor) touching the string, which in turns decides the pitch of the note on a major scale spanning 3 octaves. The higher the hand is on the string, the higher the pitch of the note will be. The force registered at the moment of attack controls three different types of sound, each being an octave apart and with different characteristics. A low force triggers a low octave bass sound, a medium force triggers a middle octave clean sound and a higher force triggers a higher octave chorus sound. If displaced enough, the accelerometer senses in which direction the string is moving, which for the low and the high sound controls a band pass filter. The frequency of the band pass filter is adjusted according to the degree of the direction (set between 0-360 degrees). A higher degree moves the band pass filter to a higher frequency. The effect is quite subtle due to the strings tightness (especially at the top), but provides a sweeping effect to the sound due to the string vibrating back and forth (between for example 0 and 180 degrees). Dragging the string in a circle motion can also control the effect.

Figure 1. Users interacting with the augmented string prototype during the user tests.

However, a downside with the ultrasonic sensor is that objects closer than 15 cm registers as 15 cm making the upper part of the string unresponsive. It also works best with flat surfaces. Striking with the hand vertically rather than horizontally therefore yields a larger risk of the sensor not registering the distance to the hand but instead registering the distance to the floor. It would be possible to use more sensitive ultrasound sensors for avoiding these problems.

Limitations

There were several different types of limitations during the design process for the prototype. Apart from producing sound, the future installation will also provide light and haptic feedback, so design decisions regarding the prototype were made in collaboration with project members focusing on those two areas as well. The optic fiber cable was chosen by the lightning design team and prevented the use of sensors covering the string, as it would obstruct the light coming out of it. It was then decided to place all the sensors at the top of the string, as to also have them out of sight and reach for the users. It was also discussed to fasten the string to the structure using springs, which would provide the string with more elasticity. Placing potentiometers in connection with the springs could then be used to measure the displacement of the string, but after discussions with the carpenter building the structure, it was decided to use another fastening method that eliminated those options.

One of the biggest challenges presented was sensing the position of touch on the string, which would be used for pitch control. Capacitive sensors inside the cable were considered for this purpose but were ruled out, as it would have required modifications of the original optic fibre cable from the manufacturers. Instead an alternative method was chosen in the form of proximity sensors attached parallel to the string. Ultrasonic sound was chosen over infrared light due to its longer range and other group members' previous experience with instability of the infrared sensors, but both would have been tested if there had been more time.

The software also provided some limitations, with issues transferring digital sensor data and certain objects for frequency analysis not working as expected. The frequencies of the strings vibrations were also too low for the piezo element to sense accurately and could therefore not be utilized for pitch information as originally indented.

It would of course have been preferable to have all of this working, but the study still yielded interesting findings.

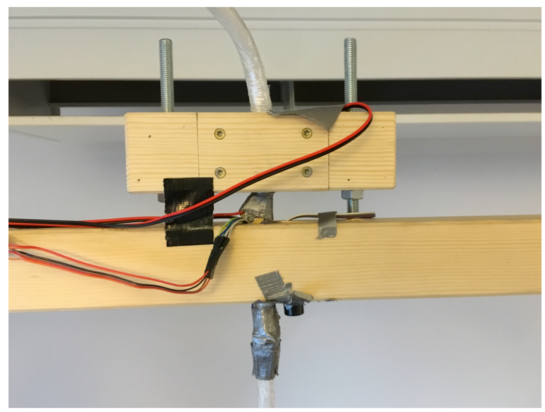

Figure 2. The accelerometer, ultrasonic sensor and piezo element mounted on the prototype cable and structure.

RESULTS

In this section I will present the thematically analysed and categorised data under the following themes discovered, *modes of interaction*, *concepts of the instrument, phases of experience* and *creative skills.*

Before presenting the results I need to declare how I define some of the interactions presented in Table 2. “Plucking” is defined as pulling and releasing the string with 2 or less fingers, while “pulling” is defined as pulling and releasing the string with 3 or more fingers. “Muting” the string is defined as holding the string to cancel its motion, while “holding” is defined as holding the string still and then releasing it. “Twisting” the string is defined as turning the string around its own axis and “dragging” the string is defined as pulling out the string without releasing it.

Modes of Interaction

All participants except the children initiated their interaction through either plucking or pulling the string while maintaining one of those interactions as their main

User	Time	Pluck	Pull	Stroke	Shake	Strike (Finger)	Strike (Hand)	Mute	Flick	Box	Hold	Twist	Drag
C1	2:00	X			X		X	X					
C2	4:50				X		X	X		X		X	X
C3	5:00				X		X			X		X	
Y4	3:00	X	X		X	X		X					X
Y5	7:30	X	X		X	X	X	X					X
Y6	6:30	X	X	X		X		X	X		X		
Y7	7:50	X	X	X	X	X	X	X			X		
P8	5:40	X	X	X	X	X	X	X	X				
P9	4:00	X	X	X	X	X		X			X		

Table 2. The participants' interactions with the prototype during the user tests. Participants' main modes of interaction are underscored.

mode of interaction. Two of the children, C1 and C3, initiated their interaction by plucking and poking respectively, but only once before moving on to other types of movements, while C2 immediately started shaking the string. The children were overall quicker to start hitting the string than the rest of the participants, and struck with their hand rather than striking with their fingers (unlike the young adults and parents who did both). The children also used less variety in their way of interacting with the string, but instead found unexpected ways (like boxing, twisting, heavy shaking and even hitting the string with their head). All children had shaking and striking with the hand as their main modes of interaction, while the young adults and parents mainly plucked, pulled or struck with their fingers on the string. All users except for C3 tried muting the string. Rare modes of interaction among the young adults and parents were flicking the string (done by Y6 and P8), stroking the string (done by Y6, Y7, P8 and P9), dragging the string (done by Y4, Y5 and also C2) and hold/releasing the string (done by Y6, Y7 and P9). Noticeable is also that none of the children pulled the string. See Table 2 for a more detailed overview.

Concepts of the Instrument

The concept of the instrument was perceived differently among the participants. Users with previous experience of musical instruments (see Table 1) overall understood the string concept and figured it would make a sound by touching it, while the rest believed it would start glowing (an expectation Y4 and Y5 also had). C2 and Y5 also mentioned however that they rather thought of a lace or a rope when they first saw it, something that C3 and P8 also did. After the initial interaction, some of the participants tried achieving different pitch by interacting at different heights on the string. Y5 thought it would be like a piano with low pitch in the bottom and high pitch on the top, which C3 and Y7 also believed. Y6 had a similar interpretation, but instead referred to the guitar's fret board. The rest of the participants discovered the idea of different pitch at different heights as they went along, except for C1 who did not discover it at all and C2 who thought the pitch varied depending on from what direction he hit it. Y4 and Y5 felt that they could control the volume of the sound depending on the force they applied when striking the string, while Y7 expected it to be like that but did not feel the system responded in that way. Y5, Y6, Y7 and P8 were also curious whether the direction from which they hit the string had any effect on the sound.

The different types of sounds were noticed by all users, but were overall not an attribute they expected. Y5 said it "*was exciting, as there was more to discover*", an opinion that was shared by C3, Y4, P8 and P9. None of the users figured out how to control it until after they got an explanation of how the different sounds were triggered, which Y6 claimed felt confusing. Y7 also felt that triggering different sounds depending on the users force caused the individual sounds to lack dynamics, as you change the sound if you hit harder instead of just increasing the volume. She still believed though that it was interesting to get more than one type of sound from the string.

Y6 and Y7's perception of the instruments complexity also differed from the rest. They felt that the instrument was very complex, with Y6 expressing that "*it's usually easy to understand the concept of a new instrument, but it was harder here*", while the other participants perceived the instrument as "easy" because "*you just need to touch it and there comes sound*".

The wah-wah filter seemed to be an appreciated element in the instrument as C1, P8 and P9 all uttered "Cool!" when they discovered it. Y7 also reacted to it, saying that at least "*this feels like I can control*". Both C2 and Y4 also seemed to be in control of it, dragging it back and forth or shaking it several times, controlling the intensity of the filter.

Y4, Y6 and P8 expressed the desire to be able to play more than one note or sound simultaneously on the string, in order to be able to play a song and not just a melody, or to be more than one person playing it. C1, C2, C3, Y4, Y5 and P8 also expressed the desire to have more strings, like a harp or a piano, for the very same reasons.

Phases of Experience

In the initial phase of the experience the participants overall expressed curiosity and excitement. Some (Y4, P8, P9) laughed for themselves while interacting with the string and some (Y1, Y3, Y4, P8, P9) uttered sentences like "*this was cool*" or "*this was fun*". Y5 and Y6 explicitly noted that the string was "*very conspicuous, you just want to go and touch it*".

After achieving sound, the way of interacting with the string differed quite a lot between the children and the other participants. The children were noticeably very intense in their interaction, using fast and energetic movements without much time for pauses or apparent reflections. The young adults and parents were much more thoughtful and thorough in their approach, taking their time to reflect on their interactions and covered most of the more expected ways of interaction (as seen in Table 2). The children were mainly concerned with creating and discovering sounds, and while C3 wanted to continue playing after the interview, C2 felt that "*it was fun in the beginning, but then you got tired of doing the same thing all the time*".

The adults (and C2) all tried to figure out how to control the sound in order to play a song or a melody, but no one succeeded. Y4 said that the pitch "*felt random*" and Y7 believed she was activating a predetermined loop. Y7 in particular became frustrated as she initially was excited and hoped that she and the string would "become friends", but as that never happened she instead started to wonder whether "she was stupid or the string was stupid". Y6 also became irritated, claiming that "*the string decided what note to play, not me*" and expressed weariness due to lack of control. In contrast, Y4, Y5, P8 and P9 all enjoyed playing the instrument and thought it was very fun despite not being able to control it as expected, and even though Y4 felt that the pitch was random he was impressed and felt that "*it's cool that you can do so much with something as simple as touching a thing*". Instead of blaming the instrument for lack of control, Y5, P8 and P9 all expressed that if they had been more musical they probably could have played it. P8 also felt that "*it doesn't need to be so serious*" in response to playing a melody, and that "*it's just cool to play around, even if you don't have control, just to create sound*". P9 also agreed that "*the drive was at first that it was fun creating sound*" but that it evolved into a desire to play a song. For Y5, Y7 and P9 this became like a problem they wanted to solve, and while Y7 got frustrated and desired a shorter "learning curve", P9 felt that if it had been easier playing a melody she would have been "finished" with the installation quicker.

Creative Skills
As seen in Table 2, users generated several different ideas of interacting with the string. Practically all of the ideas displayed during the user tests related to touching the string in some way, except for one idea Y7 had who thought her position in regards to the string might have had an affect on the sound. As mentioned previously, children showed less variation in their interaction than the adults but found unexpected ways (C3 was the only participant to hit the string with his head).

Elaborating on these ideas of interaction were hard for the users due to the lack of control, which also prevented users from creating something that they felt was original (although some users noted that it *can* be perceived as original as they, unintentionally, created something new every time"). Y7 expressed that *"It's hard to be creative when you don't have control over what notes you are playing"* and that the string *"lacked consistency".*

As mentioned previously, children were more intense and less "careful" in their interaction, hitting and shaking the string with a lot of power compared to the other participants. Y4 and Y7 both felt that they dared to hit harder and interact in ways they probably wouldn't have with other string instruments, and Y5 also said it felt easier to hit and pull this string than other instruments, as "*there's norms and rules for traditional instruments that don't exist yet for this one*". Some users (Y5, Y7 and P8) felt limitations however, like not wanting to pull it out too much or shake it too hard in fear of destroying the instrument. There was also worries about hurting oneself, portrayed by one participant (C3) who said, *"doesn't that hurt?"* when the author showed the effect of flicking the string during the interview.

While most participants said that they were too focused on finding out how the string worked to think about anything else, the installation triggered the imagination of some users, like those wishing there more strings so they could play the instrument like a harp. One user also said she felt like playing the string as an upright bass, or to have the string horizontally and play it like a piano.

DISCUSSION
The study was designed to investigate interaction with a large sized string instrument in a public setting. Even though the prototype of the augmented string did not provide the reliability that was initially aimed for, and certainly affected the way users interacted with the string, what they could control, and what they expected from it, the results still provide relevant insights into string interaction for museum settings.

Levels of Engagement
The results support the ideas of layering the experience and allowing for different levels of engagement, as shown in previous studies [1, 5, 16, 19]. For an augmented instrument in a public setting, this gives rise to some particular challenges as designers need to consider the age and musical backgrounds of their potential users, as it will affect their interactions and expectations. Depending on whom the experience will be designed for in first hand and what level of engagement that is desired for the particular exhibition, certain compromises regarding the instruments functionalities might have to be made.

For initial engagement, an early success experience is crucial for maintaining interest in the exhibit [16]. This can be achieved by utilizing the affordances of the instrument. As the most natural affordances of a string is plucking and striking it, our string produced sound just by touching it, which excited users and made them immediately curious.

This is an attribute that is referred to as "attractors" by Edmonds [10]. For prolonged engagement, the system needs to give the user the opportunity or desire to explore, experiment or challenge themselves, attributes that Edmonds refer to as "sustainers".

Exploration

The augmented string offered elements of discoverability through different types of sounds and effects that could be triggered. The users could explore these functions by interacting with the string in various ways. The way our participants approached the string seems to depend on their musical background and age (or more precisely, the lack of certain experiences, rules and norms that you obtain as you get older). The children interacted with the string more intensely, while adults had a more thoughtful approach and at times stepped back from the instrument in order to reflect on their actions and the strings responses. The children's seemingly less reflective behaviour can perhaps cause them to be guided by the design of the system, if they are continuously "rewarded" by a certain interaction. With traditional string instruments, the volume is directly proportional to the amplitude of the strings vibrations, which can be dampened more easily when striking the string with the hand instead of plucking or pulling it. The risk of dampening the strings vibrations was not the case with our string as the volume instead was connected to the force applied by the participant when the piezo detected an attack. This, in combination with the lack of (or a different) conceptual model of how string instruments work, might be the reason to why none of the children pulled the string, and only one child plucked the string before quickly moving on to more intense interactions. This less reflective behaviour is worth taking into consideration if a particular interaction is desired by the designer, and certain limitations might need to be set in order for children to not overlook "less-rewarding" interactions. The children's lack of certain behavioural rules and norms might also be the reason for their more unconventional ways of interaction, such as boxing, kicking and hitting the string with their head. These types of unexpected interactions can be important to take into consideration when designing for public installations, and decide whether or not to treat them as possible issues (if users can hurt themselves) or opportunities which can trigger rare functionalities or reveal mysterious information [3]. Seeing how the children were more focused on exploring than on completing a challenge (like playing a melody), it can be important to provide discoverable functionalities and sound effects for their unconventional interactions in order to encourage prolonged engagement. Basic musical characteristics like duration, volume and timbre should be connected to more common modes of interaction as a way to keep the users explorative journey moving forward to the next levels of engagement; experimentations and challenges.

Experimentation

The participants could experiment with the functions that they discovered when playing with the string by testing their controls, range and limitations, such as the duration, pitch or volume of a note or how to trigger the different sounds. This type of engagement was more obvious among the adults than the children, especially among those with more musical experiences, who for example expected a different pitch at different heights of the string (associating it with a guitar or a piano), or that the direction they hit the string from should affect the sound. The most common type of experimentation among the adults was trying to achieve the same note by hitting the string at the same place or with the same force, but instead it yielded unexpected results. The children were also seen hitting the string at the same place consecutive times, but perhaps for a more explorative reason due to its "randomness" (being "rewarded" with a new sound with almost every strike), as none of them explicitly tried to control the sound in that way in order to play a melody (unlike all the adults). Some users noted a difference in volume depending on the force applied, but the correlation was unclear. This was probably because the force also triggered different sounds, thereby also disturbing the sounds perceived dynamics. Most users did not experiment with the length of dragging the string, but one participant who did manage to control the wah-wah filter quite efficiently, suggesting that this is a feature that could be more prominent (interestingly, the wah-wah filter was not designed with this interaction in mind, instead it was intended to be activated by shaking the string).

Challenges

While there was no apparent goal with the string that participants were supposed to accomplish (which one participant complained about), they were free to come up with their own challenges. Although this was not deliberately or unwanted, a challenge will result in one of two outcomes: failure or success. One assumption is that failing a perceived simple challenge may lead to an unpleasant user experience, no matter how engaging. This is where the musical background of the users may play a part, as those who are more musically experienced will most likely perceive a musical challenge as easier than those who are less musically experienced. The most common challenge among the participants was as previously mentioned to play a melody or a song, but some users also tried to play several notes at the same time. The reason that these particular challenges arose was partly because the design of the system provided the users with those ideas. Due to the augmented strings natural associations to traditional string instruments, the inclusion of pitched sounds probably lead to the users (mainly adults) expecting to be able to play a melody. Some users also thought these pitches (or the different sounds) could be played simultaneously, due to the same associations. When users failed with these self-imposed tasks, most of them still felt they had a fun experience, exploring and experimenting, but wished they were more "musical" in order to succeed with their challenge. But for the users who felt that they were musical enough, not completing the task frustrated and irritated them.

A challenging element has the opportunity to be what Edmonds refers to as "relaters" [10], aspects that causes users to return to the exhibit, either driven by the sense of accomplishment or the determination to try again in case you have previously failed. But the difficulty of such a challenge needs to be balanced. According to Csikszentmihályi's flow theory, one must have a good balance between the perceived challenge of a task and one's own perceived skill level to achieve flow and avoid feeling bored or worried [8]. If it is too hard users can become irritated and frustrated, but if it is too easy to accomplish the task, users might leave as soon as they are done and not explore other aspects of the installation (as shown in previous studies [5]). Providing a too apparent (and easy) challenge may therefore conflict with the intended explorative aspects of the installation, not only for adults but for children too.

Enabling Opportunities for Creativity

Engagement has a clear connection to creativity. Exploration generates new ideas and perspectives and experimentation, driven by curiosity, makes you elaborate on those ideas. The results from the study also shows that those who spent more time with the installation also tried more different ways of interaction, suggesting that longer engagement increases the generation of ideas. But measuring the capabilities for an installation to encourage creativity in users is difficult, as each user have a different level of creativity. In this study I analysed what creative skills were displayed by the participants during interaction with the string to see if any general conclusions can be drawn in regards to the opportunities for creative thought provided by the augmented string.

Several different ways of interacting with the string was performed by the participants, compared to just plucking or striking, which are the typical ways of playing a string. As one subject expressed, *"there's norms and rules for traditional instruments that don't exist yet for this one"*. So while the string metaphor was intuitive enough for users to initiate interaction, our instrument was different enough compared to a normal string instrument to cause the participants to approach it with a different mind-set and be more explorative in their interaction. The visual differences of our string compared to a normal string, mainly its size and material, also made them curious about what it could do and how it would sound like. Its association, on the other hand, to a normal string made some users imagine playing on other types of string instruments, such as pianos, guitar, harps and upright bass, and there seemed to be a sufficient balance between separation and association in order to trigger both their curiosity and imagination.

Elaborating on the users' musical ideas proved to be difficult due to the lack of control that was caused by poor functional design in the prototype (such as the different sounds triggered by different force and unstable distance measuring determining pitch). Sensors with good resolution were used to capture a wide range of the users motions, but the sensing methods were not reliable enough to provide a responsive and expressive output. While it is difficult to talk about originality in regards to the users' ideas of interaction, due the low amount of test participants and the study setup, it is notable that none of the participants felt that they could *create* something original. This was because they were not able to elaborate on their previously discovered ideas. It was especially the uncontrollable pitch that users felt prevented originality (which is not surprising as humans have been shown to be much more sensitive to differences in pitch than for example loudness [34]), and as expressed by one of the more musically experienced users, "*was the main obstacle for being creative*".

Lastly, I believe an important aspect of this installation in order to encourage creativity is to encourage the user to *take risks*. Being perceived as different can be considered a "risk" in some adults' eyes, as we have learned certain cultural behaviours in order to "not stand out" (I find it very unlikely to see an adult kick or hit the augmented string with their head, like the children did, for example). Taking risks also determines to what limit you go when you elaborate on your ideas and how you choose to approach something new and unfamiliar. While I do not think any part of the design will cause adults to hit the string with their head (except for a sign explicitly telling them to do so, maybe), the perceived stability and endurance of the instrument certainly affected the interaction. Users do not want to break the installation (not adults at least) and they do not want to hurt themselves, so providing materials that let users dare to explore, experiment and push the limits, of the installation and themselves, is key to encourage risk taking and creativity.

Method Discussion

The choice of interviews and observations in form of video analysis as methods was a suitable combination. The video provided added details to look at based on the interview data, while the interviews provided thoughts and meaning to the video data, adding more insight to their experiences and actions. The interviews proved to be extra important as few thought aloud during interaction, as was instructed. Users may not have felt comfortable talking to themselves alone in a room, or forgot about it during interaction (as some were seen thinking aloud only in the beginning). Contextual inquiry could have been used to enforce reflections in the moment instead of relying on their memory during interviews, but the presence of an observer would also mostly likely affect the user by either putting pressure on them or making them feel uncomfortable.

The number of participants in the user tests might have been too few to draw more general conclusions due to the wide spread of the museums target group (children, parents, adults with musical interest). A more focused study on either of the subgroups with around 8 participants from each would have provided more reliable conclusions. But considering the scope and time limit of the study, the broad initiative will hopefully serve as useful groundwork in order to provide suggestions and guidelines for more in-depth research and further iterations of the prototype.

Suggestions for Improved Interaction

As a first suggestion a refinement of the prototype is needed in order to make it more controllable. For instance, providing a way to control pitch is vital to support creating melodies. This needs to be solved by using other sensing methods or evaluating other types of interactions suitable for controlling pitch (although research suggests that people associate difference in pitch with difference in elevation [30]). Time-domain Reflectometry could be an interesting method to try for this, but would require a lot of technical knowledge to implement. Pitch control could also be omitted from the instrument and instead provide an explorative soundscape, but might not create an equally engaging experience for musically experienced users. Implementing a predetermined melody loop might also be an option, but can have a negative effect as the instrument loses some of its open-ended qualities. As one user expressed in regards to the pitch feeling random, "*it feels like the string decided what note to play, not me*". A predetermined loop will do exactly that and might evoke that same limiting feeling, which might be worse than omitting pitch completely, at least for musicians. A predetermined loop can also have the effect of implying a too apparent task (play the melody) and cause users to not explore the rest of the installations capabilities once they have accomplished that.

Seeing how interactive exhibits are especially attractive to children and their families [17], it would be of interest to design for collaborative interaction and see how that affects the user experience. Research has shown that designing for collaborative exploration encourages social interaction [15], but it is important to make sure that features do not allow for users to interfere with one another [1]. This could be a challenge when only using one string, and it might therefore be wiser to apply collaborative functionalities for the full installation with 5-7 strings, rather than for each string. Research has also shown that it can be sufficient to design for co-presence rather than collaboration if the aim is to provide an engaging user experience [14], which is one of the main objectives for this installation.

The prototypes intuitiveness, how well it allows for initial engagement, was not evaluated in this study as participants were explicitly told to interact with the string. As this is the first step for interaction, more research is crucial (preferably in a real museum environment) to see if people even dare to touch the string, especially as the results suggests that the string metaphor was not fully intuitive for everybody, perhaps depending on their age (C2 for example, who first thought of a lace, started shaking and hanging in the string instead of plucking or striking it).

One of the most appreciated and engaging elements of the instrument among the participants was its discoverability. This element should definitely be retained by providing explorative sounds or effects for less common interactions (like kicking and heavy shaking), while keeping fundamental functionalities (like volume and/or pitch) to common ways of interactions, unlike the design for this prototype where changing the type of sound interfered with the control of the notes volume.

CONCLUSION

In this study I have looked at how people interact and experience a large size augmented string instrument from the perspective of creativity and engagement in a public setting. In line with previous research the importance of layering the experience has been highlighted. The study suggests that this can be achieved by designing for different levels of engagement for users depending on their age and musical background, as well as the importance of encouraging risk-taking and elaboration to allow for creative interaction.

The instruments affordances need to be utilized to ensure initial engagement and induce curiosity with the user. The explorative elements of the installation proved to be the most engaging among children, therefore it is important to design discoverable functionalities for their intense and sometimes unconventional ways of interacting with the string. The self-imposed challenges created by adults needs to be treated in a satisfactory but balanced way, in order to allow for creating their own melodies. To make sure that users dare to explore and experiment with the string, it is important that the instrument is perceived as stable and enduring, as well as unfamiliar enough for users to not be restricted by their previous conceptual models of string instruments.

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