Enhancing VR experiences with blowing input techniques

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ABSTRACT
Virtual Reality (VR) has strongly emerged to be one of the technologies to play an important role in areas such as entertainment, science, simulation and research. VR use visual, auditory and other sensations to simulate a user's physical presence in a virtual environment (VE). Adding a new layer of interaction to VR could enhance user’s immersion within the VE. This paper presents an explorative study offering insights about what factors have to be considered when designing a new blowing input technique within VR.

To carry the study two blowing input techniques were prototyped using Arduinos, one attached to the headset and one to the controller of the HTC Vive. Also eight different VR interactions were developed. Ten users participated in the user study testing the prototypes in ten minutes sessions followed by a questionnaire and an interview.

The study results show that the headset prototype was preferred by the natural way to interact with. In general the interactions were perceived as more engaging depending on the prototypes used to interact.

The conclusion is that when developing VR interactions using these blowing prototypes different factors have to be taken in consideration such as the placement and design of the virtual representation, the triggering distance, the purpose of the interaction and intuitiveness of use. It also concluded that is crucial to not use the blowing inputs in prolonged times which could cause exhaustion and/or dizziness. Finally it revealed that each prototype performed better depending on the interactions used.

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FÖRBÄTTRA VR UPPEVELSER GENOM ATT INTERAGERA GENOM ATT BLÅSA

REFERAT
Virtual Reality (VR) har starkt framkommit som en av teknikerna för att spela en viktig roll inom områden som underhållning, vetenskap, simulerings och forskning. VR använder visuella, auditiva och andra känslor för att simulera en användarens fysiska närvaro i en virtuell miljö (VE). Att lägga till ett nytt lager av interaktion med VR kan förbättra användarens försjunkenhet inom VE. I detta dokument presenteras en explorativ studie som ger insikter om vilka faktorer som måste beaktas vid utformningen av en ny blåsinmatningsteknik inom VR.

För att bära studien skapades två ingående blås-prototypstekniker med hjälp av Arduinos, en kopplad till headsetet och en till HTC Vive. Åven 8 olika VR-interaktioner utvecklades. Tio användare deltog i användarstudien som testade prototyperna på tio minuters sessioner följt av ett frågeformulär och en intervju.

Studiens resultat visar att headsetprototypen föredrog med det naturliga sättet att interagera med. I allmänhet upplevdes interaktionerna som mer engagerande beroende på de prototyper som användes för att interagera.

Slutligen visade det sig att varje prototyp fyngerade bättre beroende på vilken av interaktionerna som användes.
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Author Keywords
Virtual Reality, Input, interaction, Arduino

INTRODUCTION
Virtual reality (VR) has appeared as a new emerging industry, not only for videogames but also for areas such as research [1], science [11] and simulation [12]. Ever since its conception in the 1960’s, head-mounted virtual reality systems have been primarily concerned with the user’s visual senses and spatial audio [2]. However, VR has limited tangibility in comparison to real environments when it comes to touching objects and getting bodily feedback. A recent improvement, however, is that HTC Vive have introduced handheld controllers that use vibrotactile feedback where the user can sense vibrations when in contact with virtual objects. In addition to tactile, hearing and visual aspects, there are many other senses involved when we experience the world. For a full immersive experience, more modalities are considered better [3].

Recent technological advances in input sensing such as electronic sensors for Arduino, Virtual reality headsets and portable devices allows us to open new ways to interact with the virtual world. The unique context of on-body interaction, that could be understood as the use of the body itself as both an input and output platform, could lead us to explore new ways to interact using the advantage of these extra dimensions [3] of input that our bodies naturally afford us. One of the most frequent arguments for tangible interaction is that it is intuitive because these hybrid systems advantage user's prior knowledge from the real world. The idea that affordances improve an interface’s intuitiveness seems a direct conclusion from the definition of affordances as it is the tangible qualities of objects that allow a user to perform actions [4].

Problem statement
In this thesis, I present an approach for two new input techniques within virtual reality that could lead to better immersion in the VR world based on that blowing air with our mouth is a naturally occurring activity for humans. The techniques are a handheld blowing device and a headset blowing device for sensing blowing.

Therefore, this thesis will answer the following question:
What factors and experiential challenges emerge when designing VR interactions coupled with a mouth blowing input technique?

RELATED WORKS
Blowing force - Interacting with the mouth in virtual environments
Hands-free input techniques provide a fast, secondary input options, especially when hands are doing another task [10] or even when hands cannot be used as the case of physically impaired people [12] and could be a proper Non-verbal vocal input (NVVI) method to enhance their interaction capabilities. Blowing, which is the action of expelling a current of air from the mouth [11], is one such hands-free interaction and several research projects has look into using this for interaction. For instance, the “Fun with blow painting!” [5] allows children to paint in a digital
goals of the project was to reduce the discomfort of hand-mounted devices and allowing them to manipulate virtual objects with just bare hands. Their results showed that all tested virtual objects, except the chess pawn figure, were almost as natural to manipulate as real ones.

Non academics has also been developing approaches using low cost electronic devices such as Arduino. For instance, Yanman [*] has developed a device capable of detecting a bicycles revolutions per second and transform it into virtual movement through a VR environment. This was done by detecting how fast the legs were moving and transforming that movement into a virtual movement. Furthermore, Matthew [**] has developed a system using Arduino to recognize leaning and body movements on a skateboard and translate these inputs into movements or jumps into the VR world.

**METHOD**
To conduct this research and analyze what factors have to be considered when designing VR interactions using mouth blowing two new blowing input techniques and VR environments were developed with the purpose of setting up an explorative study. These will be explain in more detail after a more general description of the study.

**Overview of the study**
The general idea for the study was to have users experience different blowing input techniques in VR while conducting a series of different interactions to look closer at how different types of interactions based on blowing are experienced and discuss which factors affect these experiences. Therefore, two different blowing prototypes were developed with 8 different VR interactions grouped within two ways of blowing: burst and sustained. For each session users had a limited time to interact with the different interactions and both the VR interaction and the users were recorded for further analyze. After the session a questionnaire was answered and a semi-structured interview was held.

**Study design**
The two blowing input techniques were attached to the headset and to the controller. Both virtual environments were closed rooms of 2x3 meters (see figure 2). The first environment consisted in five different VR blowing interactions: a wind turbine, a dandelion flower, four big coloured spheres, three candles and a billiard balls interaction. The second environment consisted in a dragon breath and a bubble expeller and a ball shooter. The different interactions were specially chosen to offer a wide variety of interactions for the user.

For the study, a gender balanced group of 10 people aged 20-30 with no experience in VR technology was recruited. The participants were informed about the voluntary participation, the possible VR sickness and their right to

panel using their blowing force against a tangible toy. User’s expelled air from their mouths were converted into motion by a windmill and transformed into electrical signals to paint on the screen. The results show that the system was adequate to support an engaging experiment in play, creativity and tangible interaction.

A complementary approach working directly with the digital canvas Shwetak N [8] developed a blowing interface where the user could directly blow towards the computer screen and have different responses depending on the part of the screen that was blown on. It allowed actions like selecting and dragging objects, scrolling the screen and also brought the blowing natural as to be used in video games or entertainment like blowing the candles of a birthday cake. The results showed good accuracy, but some improvements in noise reduction was needed in order to be used in noisy environments such as outdoors. Similarly Daniel Zielasko [9] has developed a system named Blowclick which substitutes the common action of clicking with a finger by blowing. Clicking was instead triggered by blowing into a microphone and the main purpose was to offer a new free hand user interface for a greater immersion in virtual environments. Their results showed that it was a suitable solution for a hands free input method but also that blowing was perceived as exhausting so it could potentially lower the use of this input method as a secondary one.

Resembling the Blowclick project system, Wei-Hung Chen [10] proposed a new blowing input method for smartwatches, offering the possibilities of a hands-free interaction between the user and the device. The blowing was combined with actions like the device state (rotation and tilt) and transformed into different responses such as touching, play/pausing music, and take a picture among others.

**Body movements - Interacting with the body in virtual environments**
There has been several attempts to create natural interaction between the real and the virtual world by introducing new input and output modalities. One example is “Armura”, a project developed by Chris Harrison [6], it is an interactive on-body system that supports both input and graphical output. Using arms and hands interaction their system is capable to understand different shapes and movements and give visual feedback about the interaction. The main goal of the project was to explore the design space of arm and hand-driven interaction. The resulting prototype is shown to be capable of recognizing several arms-hands positions and give accurate visual feedback according to a predefined gesture database.

Another example is Mie Sato [7] who developed an Augmented Reality (AR) system that let users rotate, grasp, translate and release virtual objects (a sphere, a cube, a duck, a cup and a chess pawn) in the real world. The main

* https://pauldyan.wordpress.com/2016/01/24/my-vr-bike/
** http://www.instructables.com/id/DIY-Virtual-Reality-Skateboard/
quit the study at any moment. They also had to sign a consent form to be able to record them during the sessions.

Each session lasted for 10 minutes (5 minutes per device) and users had complete freedom to interact with the VR interactions in any order. For the first environment the user only need to use the prototype to blow (the headset or the handheld) but for the second environment the user had to use also the trigger of the controller to change between interactions (dragon breath expeller, bubble expeller and ball shooter). Each user started with a randomized prototype to not allow a learning effect affects them. All the VR interactions that consisted in changing the original setup of the interaction were automatically reset after a few seconds. Users were encouraged to repeat any VR interactions, to explore, to change positions and postures (See figure 1), to try different approaches to the VR interaction in definitely to do what they want within the 2.5 minutes time limit per environment for each device.

During the session users were also encouraged to think aloud and hand notes were taken of these comments. After each session each participant completed a questionnaire to quantify the experience within four aspects: ease to learn of use, fun, accuracy and effortless. Users had the opportunity to rate them from 1 to 5 where 1 was the lowest level of agreement and 5 the highest. After, an open interview was held for about 15min to go deeper into their experiences.

The data was analyzed by comparing their experiences and reactions with the two devices for each VR interaction grouped into two ways of blowing: burst and sustained. How user achieved or failed each interaction and if repetitions were needed was checked. How users approached to each interaction was noted as long as postures, positioning and movements. Finally the data from the questionnaires and the interviews were checked to further analyze the experiences.

**Prototypes and hardware**

The virtual reality headset HTC Vive, one VR controller and Arduinos hardware was used in the study. Each input technique was prototyped using Arduinos and a flex resistor sensor which consisted in an array of metal pads that changes the electrical resistance when bended. The flex sensors had a squared paper of 5cm x 7cm attached to them to strengthen the interaction by adding air resistance, much like a sail in a sailing boat. One of the prototypes was attached to the HTC Vive headset and the other to the controller (See figure 4.). For the purpose of helping users to interact with the handheld prototype a 3D representation of it was modelled.
After doing a pilot test to check the accuracy and response of the prototypes some problems were encountered. The position of the head mattered in terms of accuracy for the headset prototype. This was solved by decreasing the sensibility of the sensor. Also to increase the reliability the sensor was fixed a bit tighter to the headset. Regarding to the handheld prototype the visual representation caused problems of 3D positioning in the real world causing false positive results because of the thickness of the headset. To reduce this problem, users were taught how to hold it properly beneath their chin (see Figure 5 bottom right).

VR environments
The VR scenes was made in Unity 5 and used the SteamVR plugin which helps communicating with the HTC Vive.

Range triggered burst blowing interactions
These interactions consisted in a short blow force interactions made against 3D objects in the VR environment. The distance between the user and the object determines when the interaction is triggered, when a minimum level of blowing force is used and the minimum range within between the user and the 3D object is crossed, the interaction is triggered. These interactions were designed to be blown in short bursts and to give instant VR feedback to analyze how users experience a simple blowing interaction. The interactions included in this category are:

- **Dandelion flower**: the original state simulates a dandelion flower, when it is triggered a particle effect simulating the seeds spreading begin to appear (See Figure 6 top part).
- **Candles**: the original state simulates three lighted up candles, each one has its own triggering range, when triggered the flame is extinguished. (See Figure 6 bottom part).

Directional force triggered blowing burst interactions
These interactions consisted in a short blow force interaction made against 3D objects in the VR environment. The main difference from the previously described interaction is that is direction and blow force sensitive, so the outcome depends on where, and how much, blowing force is used. The interactions were designed to be blown in a short burst but offer the user a way to explore different approaches to interact with the 3D objects with different outcome. So different postures, positions and movements can help the user to examine the interaction. The interactions included in this category are:

- **Billiard balls**: resembling a billiard game, a white ball and 6 coloured balls are displayed on a table. The original position of the balls can be seen in the bottom left in Figure 7. When the white ball is blown on it gains speed depending on the blowing force used and begins to move away from the user. The white ball can hit other coloured balls and the physical impacts was simulated.
- **Big coloured spheres**: the interaction consist in four big spheres coloured different depending on its size. Each size determines a different mass for the sphere, the bigger the heavier. The original position of the spheres can be seen in the left top part in the Figure 7. When the user blows on them they gain speed depending on the blowing force used and in the opposite direction where the user was. Balls can collide between each other. The difference within the billiard balls is that the four of them can be blown separately, or at the same time, depending on the position of the user.
Sustained blowing interactions
These interactions were based on a sustained blow force interaction where the user can keep blowing to generate a continuous effect. With the exception of the wind turbine that has to be blown against its VR representation the rest of the interactions just appear from the prototypes, so when users blow the effects emerges from the headset or the handheld in the VR world. These interactions were designed to be blown in a sustained blow force and to give instant but continuous VR feedback to analyze how users experience an uninterrupted effect. The interactions included in this category are:

- Wind turbine: The interaction consist in a small city representation with a wind turbine. When the wind turbine it is blown it lights up the lights of the city. Depending of the blowing force the lights will be more brighter or less (See Figure 8. bottom part). The effect last until the user stops blowing and then the lights turn off.
- Dragon breath expeller: The interaction simulates the effect of expelling flames from user mouth giving the sensation of being a dragon (See Figure 10.). The force used when blowing affect how far the flames arrive. This interaction can interact with a forest that is located in the same scene, if the flames touch the trees, they start to burn, after few seconds the fire is extinguished.
- Bubble expeller: The interaction resembles the effect of expelling bubbles from the mouth of the user, similar to a bubble toy (See Figure 8. top part). The force used when blowing affect how far the bubbles arrive.
- Ball shooter: The interaction resembles the effect of throwing balls from user's mouth. The balls are affected by gravity so they describe a parabola, depending of the blowing force used their speeds varies. The balls can interact with the boxes spread through the scene, if the balls hits a box it transmits the physical force to them simulating what could happen in reality. The frequency of the creation of the balls is 4 balls per second blown.

RESULTS
In the following section the result from the study will be presented. Firstly the results from the questionnaire will be analyzed and presented. After this the results of the interactions will be presented regarding the interactions that users did, a comparison between the prototypes and how users interacted in new ways. Finally the results from the interviews will be given showing the final feedback and thoughts from users.

Questionnaire responses from both input techniques
Based on the questionnaire the two input techniques can be compared in terms of ease to learn of use, fun, accuracy and effort needed. Regarding on learning difficulty, the headset prototype got a mean value of 4.8 instead of the mean value of 3.8 for the handheld. Indicating that the headset was rated as easier to learn. With respect to the fun they had with each device, the headset got a mean value of 4.8 and the handheld a value of 3.9. Indicating that the headset was rated as funnier to interact with. In reference to the accuracy of the blowing prototypes the headset got a mean value of 4.2 compared to the 3.4 value for the handheld. Indicating that the headset was rated more accurate than the handheld. Finally regarding if the device was effortless to use, the headset prototype got a mean value of 3.9 and the handheld a mean value of 3.1. Indicating that the headset was rated as needed less effort to use it than the handheld. In the figure 9 a bar chart summary of the results of the questionnaire can be seen.
User interactions within the VR environments

In this section how users interacted and reacted using the two new blowing input techniques and the VR interactions will be shown.

The dandelion flower was usually the first interaction that the users tried, this was probably because of the starting position of the VR session as they began just next to it. Most of the users tried to interact with the dandelion flower more than one time to figure out how interaction was triggered (See Figure 6.). The main difficulty was to get in a proper position to succeed, this was usually found after leaning forward and getting close to the flower with any of the prototypes.

The candles was the interaction with most failures both with the headset and the handheld, mainly because the distance needed to blow the candles out was smaller than the dandelion. This might be the reason behind that half of the users tried two to three times without success and then moved on to another interaction. In fact, few users actually succeeded to blow the candles out, the reason was that they leaned too close to them reducing the distance between the candles and their head. After some problems to blow the candles out all together, some users instead succeeded by blowing one or two of the candles at a time using both prototypes.

The billiard game was tried several times using both prototypes by most of the users, they also tried to get different angles each time too see how the billiard balls reacted when the white ball hit them. Occasionally the white ball was not reseted properly and users had to wait for an unexpectedly long period of time, usually moving to another interaction before coming back to this one. Most of the users tried to hit as many balls as possible with one blow after having learned to blow the white ball (See Figure 7 right part). In this way the interaction appeared to trigger a desire to continue to explore this interaction further. Some of them also tried to keep blowing the white ball when moving (that was not possible), or even tried to blow on other balls. This is interesting, since it indicates that as soon as the blowing interacting was introduced, they expected that this technique would apply to other similar objects and continue to work in a consistent way on these objects regardless of state. Some users kneeled in front of the white ball to get a better view, direction and angle to blow it out as can be seen in the left part of the Figure 1.

The big colored spheres similar to the billiard game was explored several times by all the users using both prototypes. Possibly because of the extra layer of interaction given by the collisions between the balls, allowing richer interaction. Six users only succeed to blow some of the balls instead of all of them together. A problem with the implementation was that the yellow giant sphere sometimes got stuck below one of the virtual tables and didn’t reset its position properly. All of the users waited until the position resetting but the yellow ball never returned to the original position, they were advised to continue with the session without that ball. Three users tried to blow the balls when they were laying on the floor after being hit by the white ball, but no further movements occurred (they were not implemented to be blown). After this they were advised about how the interaction should be done by blowing only the white ball.

The wind turbine interaction similarly to the giant spheres and the billiard balls induced users to try new ways to interact. Three users tried to blow the wind turbine from different directions to see if direction affected the rotation of the rotor. However, those who explored blowing from different directions usually only did this with the first prototype that they tried (it was randomized), when they later tried the interaction with the second prototype they instead did not try to blow from various directions.

The bubble expeller was the sustained interaction that was the least explored by the users as only five tried it for more than 30 seconds. This was probably because it was the least interactive out of all interactions exposed as the bubbles do not interact with anything and thus was quickly tested and abandoned for other explorations. A typical example of when users abandoned this interaction, representative for more than half of the users, was when they did not get any interactive response when trying to aim the bubbles towards either the boxes or the forest in the scene. This led all users to to wonder what the purpose was of the effect. The reality was that there was no other purpose of this interaction other than an assumption that it was fun to blow bubbles. Another interesting problem with both hardware prototypes that was mentioned by most of the users, was that they experienced that the position where the bubbles were expelled from deviated more than expected, instead of coming from the mouth they seemed to come from their eyes.

The dragon breath was stated by most of the users as one of the favourites and one of the funniest interaction to play with. Concerning the implemented interactive capabilities, all of the users succeed with burning down the forest with
both prototypes (See Figure 10 top-right part). Interestingly, most of the users tried to burn other objects within the scene, such as the boxes placed on a nearby table (See Figure 10 top-left part), and wondered why these could not burn. Typically they only tried this with the first prototype tested (it was randomized) and learned about these limitations with the second prototype. However, three of them tested this again with the second prototype seemingly out of reason, possibly to test if with the second prototype a new kind of interaction could be done. Almost all of the users tried to expel fire in different directions into the air seemingly pretending that they were a dragon (See Figure 10 bottom part) waving their heads while blowing at the same time while using the headset prototype.

Figure 10. Users trying the Dragon breath effect.

The ball shooter interaction was the most appreciated interaction in the study and all users stated that it was the most fun to play with. This was also clearly visible from the time spent interacting as the users spent most time on it in general, regardless of hardware prototype used. When engaging with this interaction, all of the users initially tried to hit the boxes in the scene to check how the physics worked when hit by a ball (See Figure 11 left part). This was typically followed by exploring how the balls behaved when applying a different blowing force. These two basic explorations were tested both with the headset and the handheld. When using the handheld prototype, most users experimented with sustained blowing to blow many balls in one blow (See Figure 11 right part). However, few tried to make short bursts to control the number of balls shoot each time instead of a continuous stream of balls being shot when a sustained blown is performed.

Figure 11. The shooting balls effect.

Comparison between the prototypes
In this section a comparison between both prototypes is shown based on the observation notes, video recordings and the suggestions from the users.

Regarding the sensitivity of the prototypes the headset was clearly stated as the more sensible one, leading sometimes to a false positive results triggering some of the interactions without intentional user action. In some cases these false positives were triggered when users leaned their heads to the floor or the ceiling. This was caused by the flex sensor of the prototype attached to the headset that was not rigid enough as it bended more or less depending on the inclination. This higher sensitivity in the headset helped in some of the cases to use less effort to trigger some of the interactions for instance the wind turbine interaction was easier to trigger the minimum level of light using the headset. But on the contrary, in general, users reported a better blowing response holding the handheld prototype, apparently by the lower sensitivity of the handheld forcing them to blow stronger and being able to control the blowing force. Using the same example users achieved a brighter light levels on the wind turbine while using the handheld due to the rigidness of the flex sensor.

As regard the usability of each prototype the headset was, in general, better than the handheld. The main problem about the handheld prototype was the extra action users had to do, positioning the handheld properly below their chin and close enough to the mouth to be able to blow it. The results also show that the virtual representation of the handheld prototype only worked when users were holding the controller in front of their eyes. When holding it below the headset, because of the thickness of it, they could not see the prototype anymore and therefore they could not properly position the controller. Some users proposed that the handheld prototype should be inside the controller instead of being on top of it, allowing them to properly position it. Every time that the users walked to another place within the VR room, or move the head from side to side, they had to reposition the handheld prototype again, making it hard to master. For the headset prototype, these problems did not appear, mainly because there was no extra action to do apart from simply blowing straight ahead, so no arms or hands movements were involved to properly use the prototype. For this reason, the headset prototype worked
better for aiming purposes in all the cases.

Regarding to the purposes of the prototypes the results show that depending on the interactions engaged with, one prototype was better than the other or vice versa. For instance, all of the users said that the handheld prototype was more natural to interact with in the VE, if they could hold or pick up the blowing interactable object, for example being able to hold the bubble expeller resembles holding a “bubble toy” and guides the interaction. Another example was that it seemed more natural to pick up a dandelion flower and then blowing it up, than having to lean towards it with the handheld held in front of their mouth. In this study, the visual representation of the handheld prototype was always the same and did not change with the different interactions. In comparison, it is interesting how the headset prototype had similar results but with other interactions. For instance, all of the users agreed that if the purpose of the interaction was to be like a “dragon” spitting fire, it should be done with the mouth and not require holding something in your hand. Another example was the giant spheres and the billiard game, as most users stated, it makes no sense to have to hold something to blow them out, it is then simpler to get close and blow with the headset.

Imagination and playfulness

In this section how users thought out of the box and created new ways to interact or play with the interactions is shown based on the observation notes, video recordings and the suggestions from the users.

Some of the interactions had a clear purpose and a specific way to interact with, such as the candles, the dandelion flower and the windmill, but the others offered richer and more imaginative ways to interact with giving users the freedom to experiment and play with them with no real goal.

For example, all of the users tried to burn everything in the scene with the dragon breath interaction, however the only thing that the flames could interact with was the forest located in the scene as stated before, but this interaction seemed to push users to be more creative and find new ways to use it just for fun or for the curiosity of trying new things. One of them even roared while spitting fire arguing that he was a dragon stating “I can imagine to be a real dragon”. Similarly happened with the ball shooter. As soon as the users realized that the balls could physically interact with the boxes, all of them tried to throw the balls on other objects in the scene.

Another interaction that opened new ways to interact were the bubbles. For instance, one user tried to make the interaction more meaningful by trying to get the bubbles passing inside of an “O” in a text placed in the environment. In addition to the giant spheres and the billiard balls interactions, some users also tried to blow on them even if they already had begin to move or when they were falling towards the floor.

Semi-structured post interviews

In this section the focus will be on user feedback, suggestions and comments drawn from the follow up interviews.

Regarding the general experience of interacting by blowing in the VR environment, users in general stated that they enjoyed it and that the blowing felt natural and fun. Most of the users suggested which future implementations could use these prototypes and they stated that gaming, teaching and simulation industry are the ones which could demand this new kind of interaction.

As regards the differences between the prototypes, all users hinted that the headset prototype felt more natural to interact with than the handheld. One reason seemed to be that it required less attention when interacting with it. This was, for instance, expressed by user number 3 (U3) who said that “I don’t need to see the device to interact with” (U3). Another example statement, in which an decreased cognitive load with the handheld was indicated, was expressed by U7 who said “I don’t need to think to use it”.

Regarding the learning curve of the prototypes, the handheld was stated as harder to master even with a proper 3D representation, U4 stated: “It is hard to locate it in 3D space”. However, the difficulty of learning to use the handheld might origin from the lack of a visual representation in the VE, as many stated that they wanted something that they could hold or pick instead of having the same visual representation (the controller with the prototype attached) for all of them. With a good visual representation, responses might have instead have been in favour of the handheld, as some experienced that it had better accuracy than the headset once mastered. However, this might also be because of the different sensor sensitivities with the prototypes.

For the question about the VR interactions, frequent response concerning their general experiences from the interactions tested, was that there was a mismatch between the force applied and the results of some of the interactions. This was particularly mention in relation to the dandelion interaction where particles always were spread in the same direction (expanding like a balloon), instead of moving to the opposite direction of the blow. A similar concern affected the candles where the flames were always extinguished in the same way (just blown out) instead of moving depending on the direction of the blown.

The candles and the dandelion interactions were fixed onto a table, but users suggested that being able to pick them up with the controller and then blow it could be more natural action instead of holding the controller close to them to be able to interact. U2 stated “it makes no sense to hold something to blow it instead of picking it up!”. This indicated a need to synchronize and co-locate the
interactable object with the handheld device to enable the interaction.

As regards dizziness and/or exhaustion, most users experienced no dizziness or exhaustion during the session but they stated that they might have if the session was longer. Some of them suggested that being exhausted or dizzy could be worse with the handheld prototype because it was harder to interact with it due to the positioning difficulties in a VR 3D space. Most users suggested to use this kind of interaction in a short time periods and not to use it as the main input for an application.

As regards potential improvements of the blowing interaction, participants commonly requested more feedback of the blowing force applied since not knowing the exact force used cause confusion when some interactions did not trigger. The participants thought that this could help understand how they were performing. Another common responses concerning the handheld prototype, was to have the sensor inside the controller instead of at the top. This was mainly to close the gap between the physical location of the sensor and the virtual aim (circle with a cross) located on middle of the virtual representation of the controller in the VE.

DISCUSSION

The results show that both blowing input techniques were a suitable method of input in VR. In general, the headset prototype performed better than the handheld regarding accuracy, effort, fun and ease of learn to use. The results also suggests, despite that the users did not suffer any exhaustion or dizziness problems, that a prolonged use of the prototypes could potentially cause exhaustion and/or dizziness. This is probably similar to how we tend to be dizzy when blowing many balloons. This indicates that when designing applications based on blowing inputs the amount of time and actions that could be performed with that techniques should be limited, so that the blowing does not become too demanding. One option is to avoid using blowing as the main interaction technique and apply it to less frequent interaction. As an example it could be used as an exciting new dimension in addition to less exhaustive interaction.

The outcome of the study also show that each prototype performed differently depending on the purpose of the interaction, showing better results and more natural interaction when the virtual interaction was working together with the hardware. This is clearly stated in the results where users argued that the handheld prototype did not make sense on most of the interactions, with exceptions like the bubble expeller where it seemed natural to hold the “bubble toy” and create bubbles instead of blowing them through the headset. This indicates that the handheld prototype could be used in situations where holding an object make sense like holding a flower to blow it out or holding a fork with a piece of hot meat to cool it down by blowing on it. On the other hand, for the headset, the dragon breath was stated as natural for the same reasons, were expelling flames like a dragon should be done by simply blowing instead of having to hold something. This shows the importance of matching the physical hardware with the intended interaction in the VE as a mismatch makes the interaction difficult to understand and becomes less natural. However, it is important to note, that some problems that appeared using the handheld prototype, might have been caused by the mismatch between the reality and the VR representations in the implementation, and the fact that we rarely use an additional object to direct blowing in real life, we simply blow where we want to blow and direct rotating our head or by shaping our mouth.

The overall results indicate that the headset prototype was stated as being easier to use than the handheld, presumably by the fact that users did not need to coordinate head and hands while using the headset in contrast by the handheld where users needed to position in a proper way to be able to both trigger the blowing sensor and direct the blow in the VE. The users also felt that the headset was more natural to interact with, which feels reasonable as we typically blow with our mouths (head). It is also important to note, that the headset does not rule out blowing interaction in which the hands might be involved, such as the bubble toy, while also requiring less attention from the user on blowing the sensor correctly as with the handheld that could be located far away from the mouth. The natural and general qualities of the headset clearly is favourable as it can sense blowing at any time and allow the software to decide on how to interpret and use the data in the VE.

The results also indicate that as soon as the users learn how to interact with the blowing technique in a particular interaction tested, they expected that this technique would apply to other similar objects in the VE in a similar way. One example was the billiard balls, were only the white ball was implemented to be blowable, and only when its position was in the starting point and not in movement, meanwhile the other coloured balls were indirectly interactable by being hit by the white ball. In other words, the colored balls were not blowable, which was expected from the users. Another example was the dragon breath that was capable of burning the forest but not other objects on the scene which was a disappointment to the users who wanted to continue to test their new superpowers. These reactions seemed natural by the fact that no instructions were given on how the interactions worked and how to use them, and users simply seemed to assume that the same action would apply to other objects. A potential remedy if the interactions are not more universally applicable, would be to provide them with a short tutorial when the interaction is introduced or other visual hints on interactable objects. For instance, brighter colors when aiming at on object could indicate that the blowing technique will work.
In general most of the VR interactions implemented for this study required that the user to come close to be triggered. This was done with the intention of making them natural as human blowing has limited reach, much similar to how touch requires the user to reach for the object. For this reason, a majority of the interactions had very small triggering distances as the implementation tried to emulate real blowing distances, e.g., the candles and the dandelion flower, and this caused many failures for the participants. Based on these difficulties for the users, and the fact that we could do anything inside a VE, it seems unnecessary to be too realistic and instead approach the design of blowing interactions from a more user experience perspective. For instance, in the interactions tested in this study, we could have allowed a much more extended area in which the interactions would have been triggered, something that would probably made many of these interactions equally as exciting. Furthermore, this brings us to an interesting discussion regarding what blowing interaction could actually be used for in VEs were there are no limits. With this in mind, it seems particularly exciting to explore new ways of interacting by blowing by escaping from the natural “laws”. Such exploration could potentially lead to new kinds of exciting and fun interactions, for example, imagine blowing down a house like in the “Three little pigs” tale, or being able to freeze an entire city by blowing it like Superman. This also make sense knowing the limited physical space usually VR experiences have.

Limitations of the study
With the method presented, giving the user completely freedom to interact with whatever interactions they wanted and giving no order or clues on how to use the interactions it limits the study to an exploratory study that offers some insights about how people reacted or experienced these two new blowing input techniques. Regarding the nature of the method used is hard to compare between users and give quantified results more than just to provide evidences on how they reacted with the VR. Additionally, the results of this study cannot be taken as evidence on how blowing input techniques in VR should be designed, developed or studied.

Future research
Possible solutions for further implementations are to make sure that the blowing input prototypes always response in the same manner regarding the position or the movements of the users. Also the sensitivity of the prototypes should be adequate to each interaction making them accordingly to the design. Triggering distances should also be taken into account when designing the interactions as long as giving proper feedback on the direction and the force used when blowing. For possible further investigations about the prototypes a more quantified method can be used to make sure that all the users do the same tasks and repeat the same interactions not regarding the order, this will grant some empirical results about accuracy, reliability and usability. As stated by most of the users the gaming industry is a clear way to go with this new way to interact. Another possible future implementation is as a new way to interact with VR for disabled people or people who cannot properly use their hands.

CONCLUSION
In this paper, I have presented a study about what factors emerge when designing VR interactions using two new blowing input techniques by developing two hardware prototypes (headset and handheld) that people have tested with eight different interactions. The results show how they reacted in front of eight kinds of VR interactions. Firstly, that the headset prototype is seen as more natural and could be more generally applied to VR environments. Secondly, that the usage of the handheld prototype is limited to interactions where users could hold or pick up an object to blow it. Thirdly, when developing VR blowing interaction it is important to consider the placement and design of the virtual representation, the triggering distance, the purpose of the interaction and intuitiveness of use. Fourthly, to limit the use of the blowing input to prevent exhaustion or dizziness. Lastly, to not be bound by mimicking real blowing when designing blowing interaction and instead put the user experience at the forefront. Exploring new intuitive ways of using blowing for interaction in VEs seems to be a particularly interesting path for future work in which blowing could bring new exciting superpowers in the virtual world.

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