Did you notice that? A comparison between auditory and vibrotactile feedback in an AR environment

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ABSTRACT
There are different ways to interact with different hardware, therefore it is important to have an understanding about what factors that affect the experience when designing interactions and interfaces. This study focuses on exploring how auditory and vibrotactile feedback are perceived by the users when they interact in a virtual AR environment. An application was developed to the AR glasses Magic Leap with different interactions, both passive and active.

An experimental study was conducted with 28 participants that got to interact in this virtual environment. The study included two parts. First the participants interacted in the virtual environment where they did a think aloud. Thereafter they were interviewed. There were a total of three test cases. One with only auditory feedback, one with vibrotactile feedback, and a third that had both auditory and vibrotactile feedback. Seven of the 28 participants acted as a control group that did not have any feedback to their interactions.

The study shows that using only vibrotactile feedback creates different impressions depending on earlier experiences with the same AR environment. Using only auditory feedback created an atmosphere that were close to reality. Having both feedbacks active at the same time reduced the noticed feedback and some interactions were here not even noticed at all. Passive interactions were more noticed than active interactions in all cases.

SAMMANFATTNING
Det finns flera olika sätt att interagera med olika hårdvaror och därför är det viktigt att ha en förståelse kring vilka faktorer som påverkar upplevelsen när man designar för diverse gränssnitt och interaktioner. Den här studien fokuserar på att utforska hur auditiv och vibrationsåterkoppling uppfattas av användaren när de interagerar i en virtuell AR-miljö. En applikation var utvecklad till AR-glasögonen Magic Leap One med olika aktiva och passiva interaktioner.


Studien visade att bara använda vibrationsåterkoppling skapade olika intryck beroende på de tidigare erfarenheterna i samma AR-miljö. Att endast använda auditiv återkoppling skapade en atmosfär som vara nära verkligheten. Att ha båda återkopplingarna aktiva samtidigt reducerade den totala märkta återkopplingen och några interaktioner hade inte någon person som noterade någon av dem. Passiva interaktioner var mer uppmärksammade än aktiva interaktioner i alla testfällen.
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Author Keywords
Human-Computer Interaction; Vibrotactile feedback; Auditory (non-speech) feedback; Augmented reality; Mixed reality; Magic Leap

1 INTRODUCTION

1.1 Interactions
Interactions in virtual environments (VE) can be either active or passive [29]. An active interaction is when the user is making conscious interactive choices with the input device. This could be, for example picking up an object or pressing a virtual button. The interactions are short and instant. On the other hand, a passive interaction is when the environment is affected by indirect interactive choices such as when the player is close to an object and thereby starts an action. This could be, for example by passing a tree and the leaves starts to move due to the motion of the player. The input device is only used as an indicator if it is close enough instead of gather inputs. Passive interactions are more often continuous and goes on until the user quits the specific interaction [28].

Nowadays, the most common way to interact is via hand controllers that creates a representation of the player’s hands in the VE. The position of the controllers are tracked by external sensors through triangulation.

Other ways to interact include using gaze and head movements, either by using the center of the headset’s field of view (FOV) or by using built in eye tracking [6]. When pressing a button using gaze, the user needs to direct their attention to the object during a certain time. Another way to interact in the VE is to use external devices that can register the movement of the player’s hands and fingers. One device that can do that is the Leap Motion [17]. Two other such devices are the HoloLens and the Magic Leap that are see-through Head-Mounted Display (HMD) that have that feature built in [21, 19].

The Magic Leap is a head-mounted augmented reality (AR) headset that uses spatial computing to track the surroundings. It uses IR sensors to scan the surroundings after furniture and walls and adapt the virtual content to the real world. The IR sensors can be disturbed by the sun’s IR radiation, which limits the spatial computing. The Magic Leap can use hand controller, gestures and eye tracking to interact with the VE. The FOV is limited to a 4:3 ratio with 40 degrees horizontal and 30 degrees vertical [30].

Figure 1. The Magic Leap One [30].

1.2 Augmented Reality and Virtual Reality
For AR, many new applications both for games and as useful tools have been developed over the last years, both in
Virtual Reality (VR) on the other hand, is a computer simulated environment that takes the help of a HMD to create a VE that gives a full immersive experience to the player. Oculus [16] and HTC [32] are two companies that are developing VR HMD. When developing content to the VE, there are three key points to take into consideration: Immersion, Interaction and Imagination. They are called the Virtual Reality Triangle and are vital [2, 7]. Missing one of these key points will result in an experience of an application that are not finished. For the Interaction key point, there are different types of tracking systems that let the user interact with the simulated environment. The number of Degrees of Freedom (DoF) represents how many movements and rotations that the device can register and transfer to the VE. A headset that have 3 DoF can only register rotations while a headset that have 6 DoF can register movements as well as rotations.

1.3 Sound and Haptics

Sound files can communicate different messages depending on the situation and type of sound source. Having two identical objects with different sounds could be used to indicate different statuses of the object, e.g. that it is functional etc. A sound file that is constantly changing could indicate that the object itself is moving. Information in sound can also be used as a tool for people with limited vision [33]. These examples illustrate the amount of information that can be transmitted via sound. This needs to be taken into consideration when designing for a VE. Placing the sound file on the objects that should emit sound can create a more lifelike experience since the sound comes from a specific direction in the VE in contrast to 2D sounds that has a global source [24, 31, 33].

The number of ways to apply haptic feedback to VE have increased over the last years. The company HaptX has developed a haptic glove that consists of an exoskeleton with the ability to apply a force of 2 kg on each finger. This gives the illusion of holding objects in a VE [12]. bHaptics is one of many companies that develop haptic vests. With the help of sensors a virtual hit can be applied through the vest on approximately the same point on the vest as in the VE [4]. Nintendo has developed a platform, the Nintendo HD Rumble, that can give directed vibrotactile feedback. One of their applications let the user guess the amount of ice cubes in a virtual glass just by shaking the controller [26].

Haptic feedback in hand controllers works different on different devices. The Oculus SDK supports both “Non-Buffered-Haptics” and “Buffered Haptics” with the difference that it can both be continuous and vary over time. [16]. The HTC Vive supports only an on/off state on their haptic system [32]. The Magic Leap includes nine different haptic patterns with three intensities [19].

Adding sound and vibrations to a VE often have the purpose of creating different impressions and emotions for the user [8]. This has been done in movies by using sound design to create impressions that helps the viewer, for example identify what genre the movie belongs to. A horror movie have a darker tone in the sounds than a comedy has [9]. Sound design is essential also in many other areas, such as in automotives and mobile phones.

1.4 Research Question

With this in mind this paper will explore the research question: What are the user experience differences between auditory feedback and vibrotactile feedback in a virtual environment and how can you design with auditory and vibrotactile feedback to enhance the interactions?

To answer this, two sub-questions were asked:

1. Is there a difference between how the user perceives feedback in active and passive interactions, and if so, what?
2. What impressions do auditory and vibrotactile feedback produce?

1.5 Delimitations

The scope of this thesis is limited to the Magic Leap device and to investigating how users perceive different types of feedback on different interactions. The sound and haptics were identical to all interactions of the same type, short instant interactions and long continuous interactions. All other factors were identical between the experiments. Even though the Magic Leap can register both hand motions and eye movement, this study was focusing only on interactions made by the hand controller.

2 THEORY AND RELATED WORK

This chapter focuses on concepts and studies that address similar experiments regarding different feedbacks in different contexts. The main focus lies on vibrotactile feedback since it involves more technical challenges than auditory feedback [7].

2.1 Vibrotactile Feedback

How the user perceives receiving vibrotactile and auditory feedback depends on different factors. In addition, how the haptics is implemented can affect the user experience. Erik Forsberg made a study about information visualization in VR where he made a design choice to add vibrotactile feedback to his interactions. Half of his participants did not notice the vibrotactile feedback and some noticed
Vibrotactile feedback on interactions for which he did not implement it on [10]. Also Hoggan et al. made a study, in 2008, where they investigated the effectiveness of having vibrotactile feedback on touch screens [14]. The first iPhone was released in 2007 [34] and Hoggan’s study therefore took place in the early days of the smartphone era. The authors measured the time it took to enter certain phrases and the amount of errors the participants made. They concluded that it took a shorter time to write on a keyboard that had vibrotactile feedback and that the amount of errors decreased with haptic feedback.

Vibrotactile feedback in virtual simulators can create an illusion of touching objects. Kristine Hagelsteen et al. investigated the performance and perception of vibrotactile feedback in a VR simulation for surgery. They showed that the performance increased with less errors and less damage when the vibrotactile feedback was active. Even though the vibrotactile feedback left an unrealistic feeling for most of the participants, their study showed that the use of vibrotactile feedback can improve the performance [11]. Something that also Pawar et al. concluded [24]. Devices that do not have input devices with haptics need additional or special made devices in order to use haptics. Leonardo Meli et al. investigated a few ways to add haptic feedback to Microsoft HoloLens, AR glasses that relies only on hand gestures instead of a controller to navigate. By only using hand gestures, it is hard to simulate a realistic touch in VE. Meli et al. concluded that adding haptic feedback in the HoloLens improved the effectiveness and the immersiveness with small vibrotactile devices on the hands compared to not having any vibrotactile feedback at all [22]. Borst et al. implemented an interaction panel for mixed reality. They combined a virtual board with a physical board, so when the user interacted they could feel the physical board [5]. Achibet at al. investigated a way to apply haptic feedback to interactions in VR, and developed an elastic-arm. Their design “provided a cost-effective alternative to active haptic devices” and have according to Achibet potential within medical rehabilitation [1].

2.2 Auditory Feedback
Using auditory feedback in applications are commonly used today. In 2005, Ying Zhang et al. compared visual and auditory feedback in a virtual environment. The auditory were split into 3D sound and 2D sound. According to their study the participants prefer to have 3D sound rather than 2D sound even though the effect on task performance was minimal. The combined case with both visual and auditory feedback got the best task performance compared to having them separate [36]. By adjusting the visual and auditory feedback can a person’s walking pace and rhythm change to adjust to the rhythm of the feedback. Justyna Maculewicz et al. studied this phenomenon and concluded that adjusting the auditory feedback had a bigger impact on the body’s pace than changing the visual feedback [18].

2.3 Compared Feedback
Some studies have compared auditory and vibrotactile feedback. One of them is Mario Romero et al. that investigated the “design and evaluation of embodied sculpting”. For their design, they concluded that auditory feedback increased the experience but when the vibrotactile feedback was active it decreased the impact the sound had on the immersion [27]. Eve Hoggan et al. have compared auditory and vibrotactile feedback in a mobile environment [13]. During the experiments, they measured the noise levels in the surroundings to see when the modalities lost their effectiveness. Their participants were asked to type on QWERTY keyboards while the sound level and vibration intensity were measured. Their results showed that auditory feedback worked until the surrounding noise level reached 94-96 dB, which corresponds to an auditory noise level of being inside a subway. Vibrotactile feedback had a decreasing performance after the surrounding noise level reached 100-102 dB, which corresponds to an auditory noise level of riding a motorcycle [23].

3 METHOD
A VE was developed for the Magic Leap in order to explore how people perceive auditory and vibrotactile feedback when interacting in an augmented reality setting. The application includes three different cases. One processed only auditory feedback, one only vibrotactile feedback, and one had both auditory and vibrotactile feedback on all interactions. The only thing that differed between the cases was the feedback that was given, everything else was the same. These three cases allow to isolate and compare the effect of the feedback. The interactions were chosen to test both active and passive interactions as well as different categories of interactions, for example, texture, temperature and motions. The choices were made so that there were no on beforehand biases regarding what feedback that was going to be better for each interaction. Conclusions could thereby be made without any bias at the same time as multiple areas of interactions were covered.

3.1 Pilot Study
A pilot study was made to test if the interactions were easy to understand and if they addressed what they were supposed to do. Also, the clarity of the interview questions was tested. The pilot study, as well as the main study, was designed with an experiment part where they got to interact with the Magic Leap followed by a semi-structured interview. The results from the pilot study showed that some of the objects were hard to find and understand. The participants spent more time searching for the objects instead of interacting with them. The objects’ appearance was improved to the main study.
For some of the interview questions the participants gave answers that did not match the purpose of the questions. The formulation of the questions were updated to better match their purpose.

Three people participated in the pilot study, two females and one male between 23 and 26 years old. They had different backgrounds and mixed earlier experiences with VR and AR.

### 3.2 Participants

The participants were recruited via an open Facebook event and through word of mouth. There were no specific target group or requirements on previous experiences with either VR or AR in the recruitment. The amount of earlier experience can affect the perception of the chosen feedbacks. By not having any requirements, that could be evaluated as well.

The participants were divided into three equally sized groups (A, B and C) with seven in each. Each group had one case they performed. There was also a fourth group, the control group that did the same test as the other participants, but with no auditory or vibrotactile feedback. After that, they were asked which feedback they thought would fit the interaction and what they missed, if any.

The 21 people that participated in the main study included thirteen females and eight males aged between 20-26 years ($s = 1.7$). Fifteen of them had not tried the Magic Leap before.

Seven people participated in the control group, two females and five males aged between 19-25 years ($s = 2.3$), and no one had tried the Magic Leap before.

### 3.3 Study Design

To ensure consistency and not affect the outcome, all user tests followed the same structure. The experiment was conducted one participant at the time and the only people present during the test were the study moderator and the participant. The study took about 30-40 minutes each and was held in the participant’s native language.

First, the participant was asked to fill in a consent form to agree on participating in the study. The consent form brought up that it was voluntary to participate in the study, that they could quit anytime they wanted, and that the collected data was going to be anonymized. Due to ethical aspects when conducting user studies, it is important to inform the participant that the participation is voluntary, which is the reason for the consent forms. The participants then filled in a form with background variables of earlier experiences with gaming on different devices and also earlier experiences with VR/AR/Magic Leap, all this on Likert scales. The scales went from 1-5, where 1 represented Never used and 5 Experienced user (used frequently). Using Likert scales gives an opportunity to evaluate the experience and to see trends. The participants were also asked if they accepted to have their voice recorded during the test. The recordings were made with the purpose of being able to go back and analyze what was said without missing details.

Before they put on the Magic Leap, they were given instructions what they were going to see in the Magic Leap and how they were going to use the hand controller. Nothing about the goal or hypotheses of the thesis were mentioned, nor what they were going to look for or feel. They were told to do a think aloud during the experiment, telling everything they did and notice. This allowed collecting the participants’ spontaneous reactions. When the participant uses the Magic Leap the study moderator can not see what the participant is doing. Therefore the think aloud is essential as it also monitor that the participants do what they are supposed to do and catch if something is not working correctly.

When the participants put on the Magic Leap, they first got to familiarize themselves with the environment. They were given instructions where they would find tools and some written instructions. These instructions include a list of nine interactions (tasks) that needed to be completed. (See 3.4 Virtual Environment and Tasks. The study moderator kept the controller until all instructions were given so that the participant could not start the experiment before all instructions were given.

The first thing they saw after putting on the glasses were three buttons representing the three cases; A, B and C. The participants were beforehand assigned one case randomly and were told to press the corresponding button. They were not told what the buttons meant. After pressing the appropriate button the experiment and the AR-interaction started. After accomplished all nine interactions, they were allowed to continue to explore or finish. The last part of the study was a semi-structured interview with questions about what feedback the participant perceived to each interaction and if some of the feedback could be improved and if so how.

After the interview, the goal of the study was revealed. They were then offered to try another case or the same if they wanted. This to see if they noticed more or less feedback when they knew the purpose of the study. This part was not part of the main study.

### 3.4 Virtual Environment and Tasks

The VE was a two floored house with different furniture and objects, shown in Figure 2. There was also a list with different tasks in a random order that the participant needed to finish, see Figure 3. They were allowed to interact freely but the minimum was to complete all the tasks on the list. The different interactions cover different aspects of interactions, both active interactions where the user is...
directly interacting with the environment and passive interactions where the user is not affecting the environment directly.

Figure 2. The VE used in the study. Image is taken from Unity3D

<table>
<thead>
<tr>
<th>Area</th>
<th>Interaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Active</td>
<td>Lift objects, Drop objects</td>
</tr>
<tr>
<td>Half-active</td>
<td>Use the magnet to pull a chest, Empty a jar, Use the fan</td>
</tr>
<tr>
<td>Passive</td>
<td>Burn the controller, Find the freezer, Touch the bushes, Lean into the house</td>
</tr>
</tbody>
</table>

Figure 3: Visualization of the areas with corresponding interactions.

For this report, the term half-active interactions covers the area between an active and a passive interaction. This is interactions where the user uses tools or objects to perform a wished interaction. An example is using a magnet to affect another object or grabbing a jar and turn that upside down to simulate emptying it.

The first two interactions shown in Figure 3 are examples on active interactions where the user is forced to use the controller and actively choose the object to interact with it, by pressing a button on the input device. The middle three are representations of half-active interactions where the user is using an object to perform the interaction. After grabbing the object, the interaction is starting either by moving the controller in a specific way or by aiming it on another object to affect that one. The last four are examples of passive interactions where the interactions are active when the user have the controller close to an object.There is no need of using the buttons on the input device.

3.5 Interview
The last part of the study was a semi-structured interview that brought up different aspects of the feedback that the participants noticed. The pre-made questions could be categorized into two categories, Perceived interactions and Perceived impressions. Perceived interactions focused on what the participants thought about the feedback they received, if the feedback fitted to the tasks, and if the participants wanted the feedback in another way. Perceived impressions focused on what feelings the feedback gave the participants, both positive and negative and also emotional impressions. Follow-up questions were asked if the participant gave interesting or unclear answers.

3.6 Software and Hardware
The study used a Magic Leap One (Figure 1) and the application was made in Unity3D (version 2018.1.9f2-MLTP10) with Lumin SDK version 0.19.

The sound files that were used for the continuous tasks, such as “Touch the bushes” and “Empty a jar”, had a windlike sound while the short instant tasks, such as “Lift objects” and “Lean into the house”, had a short click sound. The choices of sound were made to limit any associations for the sounds for the participants. Using a neutral, abstract sound instead of a concrete reduces any bias towards auditory or vibrotactile feedback. A concrete sound does often carry more information than an abstract sound and is often associated with either objects or actions. This could be the sound of wood when knocking on a door or the sound of pouring when filling a glass. Different sounds can also create different impressions. The sound of an ice cream truck could produce an impression of hunger and happiness while a siren could produce an impression of fear. Using a neutral sound eliminates those associations and impressions [9].

The vibrations had all the same setting on all interactions to avoid any bias. The setting was a low intensity click vibration [20] that for the continuous interactions looped as long as the interaction persisted.

4 RESULTS
In the following sections a noticed feedback is defined to be when the participant clearly distinguishes that they noticed a feedback and could specify what type it was. If the participant was unsure if they noticed anything or if they could not distinguish what feedback they noticed it is not counted as a noticed feedback. The information in the participant’s think aloud and interview was combined in order to create a more complete picture of the participant’s impressions. This enables to handle the situations when the participants did not say everything during the think alouds and vice versa.
4.1 Experiment

4.1.1 Group A - Sound
Group A had only auditory feedback on their interactions and had seven participants taking the case. No vibrotactile feedback was given.

As shown in Figure 4, the feedback that all participants noticed was the sound from “Touch the bushes”. This is also the interaction that most participants erroneously said they felt a vibration from.

“The bushes vibrated and sounded when you touched them” - Participant 6 [Translated]

“It [the bushes] vibrated a lot. I think they made some sound as well” - Participant 4 [Translated]

Figure 4: Perceived feedbacks in group A.

The passive interactions are the ones that are the most noticed interactions, as shown in Figure 5. This group of interactions are also the ones that most people erroneously noticed a vibration from even though no vibrotactile feedback was included in test case A. The least noticed interactions belonged to the half-active interactions. The half-active interaction that most people noticed the auditory feedback from was “Empty a jar”, while “Use the magnet” was noticed only by one person. The active interactions were the most diverse regarding noticing them. It was more common to notice a sound when you lifted an object than if you released it. There was one person that erroneously felt a vibration when lifting an object.

4.1.2 Group B - Haptic
Group B had only vibrotactile feedback on their interactions and had seven participants taking the case. No auditory feedback was given.

As shown in Figure 6 the feedback that all participants noticed a vibration from was “Burn the controller”. For the interactions “Use the magnet”, “Use the fan” and “Touch the bushes” there were only one person each that missed the vibrotactile feedback. One person noticed a vibrotactile feedback when lifting objects and two participants when dropped objects. “Burn the controller” and “Lean into the house” are the only interactions where one person each erroneously heard a sound when performing the interactions.

“I remember that. it [the fire] vibrated!” - Participant 17 [Translated]

As shown in Figure 5, the active interactions are the ones where most people missed recognizing the vibrotactile feedback, while both the half-active and passive interactions had a higher rate of been noticed. The passive interactions had a bigger spread than the half-active interactions.

4.2.3 Group C - Sound and Haptic
Group C had both auditory and vibrotactile feedback on their interactions and had seven participants taking the case.

The interaction for which all participants noticed a vibrotactile feedback was “Burn the controller”. Only one
person missed the auditory feedback for this interaction, as shown in Figure 7. “Touch the bushes” was the second most noticed feedback, for which 6 out of 7 noticed the auditory feedback and 5 out of 7 noticed the vibrotactile feedback. For “Drop objects” and “Lean into the house” no one notice neither the auditory feedback nor the vibrotactile feedback.

Figure 7: Perceived feedbacks in group C

![Perceived feedbacks in group C](image)

Figure 8: Categories Active, Halv-active, Passive interactions shows the number of people noticing each interaction and what category they belonged to. This involves both auditory feedback from group C.

As shown in Figure 8, the passive interactions are the ones for which most participants noticed feedback, both auditory and vibrotactile. Noticing vibrotactile feedback on the active and half-active interactions had almost the same distribution, while the auditory feedback had more people noticing the half-active rather than the active interactions.

### 4.2 Interviews

#### 4.2.1 Perceived interactions

In the interviews the participants answered the questions: “What feedback did you experience when you <interaction>, and did you feel that it fitted the task?” and “Which interaction(s) did you think the feedback fitted the best/worst? And why?” Both questions explored how the participant perceived each interaction. The questions about the best and worst fit resulted in Table 1, 2 and 3 where each participant got to choose one or more interactions that they thought were the best or worst, respectively.

#### Table 1: The three top and bottom rated interactions for the participants in group A, and the number of votes each of these interaction got. A total of 13 votes were cast on top and 9 on bottom.

<table>
<thead>
<tr>
<th>Auditory feedback</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Top 3 interactions with sound:</strong></td>
<td><strong>Bottom 3 interactions with sound:</strong></td>
</tr>
<tr>
<td>Touch the bushes - 7</td>
<td>Use the magnet - 3</td>
</tr>
<tr>
<td>Burn the controller - 4</td>
<td>Empty a jar - 3</td>
</tr>
<tr>
<td>Find the freezer - 1</td>
<td>Burn the controller - 2</td>
</tr>
</tbody>
</table>

All participants from group A, who had auditory feedback only, answered that the best fit was the interaction “Touch the bushes”. The second best fit was “Burn the controller”. The worst fit was considered to be “Use the magnet” followed by “Empty a jar” and “Burn the controller”. Notable that “Burn the controller” is included in both categories.

#### Table 2: The three top and bottom rated interactions for the participants in group B, and the number of votes each of these interaction got. A total of 12 votes were cast on top and 10 on bottom.

<table>
<thead>
<tr>
<th>Vibrotactile feedback</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Top 3 interactions with haptic:</strong></td>
<td><strong>Bottom 3 interactions with haptic:</strong></td>
</tr>
<tr>
<td>Burn the controller - 4</td>
<td>Use the magnet - 2</td>
</tr>
<tr>
<td>Empty a jar - 2</td>
<td>Lean into the house - 2</td>
</tr>
<tr>
<td>Use the fan - 2</td>
<td>Touch the bushes - 2</td>
</tr>
</tbody>
</table>

Those in group B, with vibrotactile feedback only, had a split view about the interaction with the worst fit. “Use the magnet”, “Lean into the house” and “Touch the bushes” all got 2 votes each while the last 4 votes were shared evenly between the other four interactions. The best fit
One person wished to receive vibrotactile feedback when sound on out of 7 wanted sound on auditory feedback on many of the performed interactions. 5 all of those who had case B, vibrotactile feedback, wanted different interactions and be more similar to the action in participants wanted the sound files to differ more between representations. One consistent response was that the since they are temperature “Burn the controller” better to have different sounds on controller” where one mentioned that it would have been and two wanted haptics on bushes”. 4 out of 7 wanted haptic feedback on the proposed compared to those who had vibrotactile feedback. The participants from group C, who had both auditory and vibrotactile feedback, did not have a majority interaction that they thought was the worst. “Empty a jar” got 3 of 7 possible votes, followed by “Find the freezer” with 2 votes. The interactions that 4 out of 7 people liked the most were “Burn the controller”, “Touch the bushes” and “Use the magnet” got 2 votes each.

On the question how they perceived the feedback and what they liked about them two people started to talk about different visual effects they liked. One from group A mentioned that the leaves on the bushes started to move when the person touched them. The other person from group B mentioned that the objects that the person lifted grew bigger and shrank back to their original size when dropped them. No one of these visual effects were implemented in the application.

4.2.2 Change in the received feedback
Four questions in the interview explored if the participants wanted to change the received feedback in any way. Those from case A, auditory feedback, had fewer changes they proposed compared to those who had vibrotactile feedback. 4 out of 7 wanted haptic feedback on the “Touch the bushes” and two wanted haptics on “Burn the controller” and “Lift objects”. 2 wanted other sounds on “Burn the controller” where one mentioned that it would have been better to have different sounds on “Find the freezer” and “Burn the controller” since they are temperature representations. One consistent response was that the participants wanted the sound files to differ more between different interactions and be more similar to the action in real life.

All of those who had case B, vibrotactile feedback, wanted auditory feedback on many of the performed interactions. 5 out of 7 wanted sound on “Use the fan” and 4 wanted sound on “Burn the controller” and “Touch the bushes”. One person wished to receive vibrotactile feedback when “Lift objects” and “Drop objects” since that person did not notice that there was any feedback on those interactions even though there was. The variation of vibrations were good according to the participants. They felt a difference in the vibrations depending on what interactions they performed even though the vibrations were actually identical between the interactions.

When both feedbacks were active there were not as many changes the participants wanted. Their wishes were mainly that the participants missed to perceive the feedback. There were 2 people that wished adding sound to “Burn the controller” and one person each that wanted sound on “Use the fan” and “Find the freezer”. One person wanted to add haptic feedback to “Touch the bushes”.

4.2.3 Perceived impressions
One question in the interview was: “Did the feedback give you any feelings or emotions when you practiced the tasks?”. The two interactions that a majority brought up on this question were “Touch the bushes” and “Burn the controller”. Both of these are half-active interactions. 7 out of 11 mentioned that the bushes felt like they were in the room and 3 of those, who all had vibrotactile feedback, got the impression that they were thorn bushes. This due to the hardness of the vibrations, according to them. That reminded them of sharp thorns instead of soft leaves. One person mentioned that the given sound from the bushes were stressful and did not fit to the soft bushes that the participant expected.

The fire gave mixed impressions to the participants. 5 out of 8 mentioned that the feedback was good and that they gave either a feeling of danger with vibrotactile feedback active or an awareness with auditory feedback. Those who had vibrotactile feedback and tried “Burn the controller” as one of the first interactions started to associate the vibration with a negative feeling later and the interactions thereafter gave a negative association and left a confused feeling, since they thought they either did something wrong or that everything were dangerous to do. Those with auditory feedback had the opposite reactions. They felt that the fire was present but did not get the impression of dangerous or negative.

“I do not think it adds anything when you burn something, because I do not associate that with any kind of friction. Like when touching a surface”
- Participant 19 [Translated]

4.3 Control Group
The control group did not have any feedback other than the visual, i.e. no auditory or vibrotactile feedback. Seven people were assigned to this group. They got the same VE as the other groups and had a semi-structured interview after.

Table 3: The three top and bottom rated interactions for the participants in group C, and the number of votes each of these interaction got. A total of 11 votes were cast on top and 8 on bottom.

<table>
<thead>
<tr>
<th>Top 3 interactions with sound and haptics:</th>
<th>Bottom 3 interactions with sound and haptics:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Burn the controller - 4</td>
<td>Empty a jar - 3</td>
</tr>
<tr>
<td>Touch the bushes - 2</td>
<td>Find the freezer - 2</td>
</tr>
<tr>
<td>Use the magnet - 2</td>
<td>Lean into the house - 1</td>
</tr>
</tbody>
</table>

The participants from group C, who had both auditory and vibrotactile feedback, did not have a majority interaction that they thought was the worst. “Empty a jar” got 3 of 7 possible votes, followed by “Find the freezer” with 2 votes. The interactions that 4 out of 7 people liked the most were “Burn the controller”, “Touch the bushes” and “Use the magnet” got 2 votes each.
One question from the interview was “What feedback had you wished that you would have received when you [task]?”. The interaction that most participants wished auditory feedback from was “Burn the controller” with 5 out of 7 people mentioning that, shown in Figure 11. “Touch the bushes” followed with 4 people. The interaction that all 7 participants wanted vibrotactile feedback on was “Touch the bushes”, followed by “Lift objects” with 5 people. There was only one person that wanted auditory feedback on “Find the freezer” and two that wanted vibrotactile feedback on “Use the magnet”.

No participant wanted any feedback on “Lean into the house” with the motivation that it would be confusing to get feedback in you hand when it is your head that is doing the interaction. 3 participant told that the feedback would have been more accurate if it was the hand that was doing that interaction.

| Desired interactions by the control group that would improve the experience. “Either” includes having only one feedback active while “Both” include having both feedback active. |
|---------------------------------|----------------|
| Lift object                    | 2              | 3              |
| Drop objects                   | 1              | 1              |
| Use the magnet                 | 2              | 0              |
| Empty a jar                    | 3              | 0              |
| Use the fan                    | 4              | 0              |
| Burn the controller            | 6              | 1              |
| Find the freezer               | 1              | 0              |
| Touch the bushes               | 3              | 4              |
| Lean into the house            | 0              | 0              |

Table 4: Desired interactions by the control group that would improve the experience. “Either” includes having only one feedback active while “Both” include having both feedback active.

“The top interactions for which the participants wanted both auditory and vibrotactile feedback on were “Touch the bushes” (4 persons) and “Burn the controller” (3 persons), shown in Table 4. Only one person wanted both feedbacks on “Use the fan” and “Lift objects”.

5 DISCUSSION

The purpose of this study was to investigate how users in an AR environment perceive auditory and vibrotactile feedback. This was made with the Magic Leap glasses and a variety of interactions. The discussion is based on the sub-questions that were:

1. Is there a difference between how the user perceives feedback in active and passive interactions and if so, what?
2. What impressions do auditory and vibrotactile feedback produce?

5.1 Active interactions vs passive interactions

One thing that was common in both A and B, auditory and vibrotactile, was that there were persons noticing the opposite feedback even though that was not implemented to them. It was more common in the case with auditory feedback to feel vibrations than hearing in the vibrotactile case. This goes in line with the results from Forsberg’s study. Some participants speculated in the semi-structured interviews that this might be due to the fact that today’s society is built on notices that most commonly has vibrations. The participants told that they are used to the vibrations of the phones and thought they had become immune to the tactile feeling due to that. Thus it is easier to ignore both sounds and vibrations when you are used to it.

By comparing the graphs in Figure 4 and Figure 6 it is clear that the participants noticed the vibrotactile feedback more than the auditory feedback, a total of 39 noticed vibrotactile feedback events compared to 33 auditory feedback events. By doing the same comparison with Figure 7 it is seen that the amount of noticed feedback decreased for both feedback, 25 noticed vibrotactile feedback compared to 39, and 22 noticed auditory feedback, compared to 33. This is in line with what Romero et al. concluded in their study, that when haptics is active in the environment there will be a decreased impact of sounds. This is also true for the opposite. By comparing Figure 7 with Figure 4 and Figure 6 again, we can see that sound decreases the impact of haptics as well. This decreasing could also be the reason why some interactions were not noticed at all when both feedbacks
were active at the same time. In Figure 2 and Figure 4, the number of participants that noticed the feedback for “Drop objects” and “Lean into the house” are already low, and when both are active, no one noticed their feedbacks.

5.2 Perceived impressions
One question in the semi-structured interviews was “Did the feedback give you any specific feelings or emotions when you practiced the tasks?” No one of those that had only auditory feedback told that they perceived any specific feeling, more than that it added realism to the VE.

Those with only vibrotactile feedback perceived more impressions than those who had only auditory feedback. Due to the random order the tasks appeared on the list, the participants started to associate the vibrations with different impressions. Those who started with “Burn the controller”, which is a negative action, started to associate vibrations with negative events or that they were doing something wrong when performing tasks. Those who started with a task not associated with anything negative, for example “Touch the bushes” or “Find the freezer” did not have that associations when they performed other tasks. They thought instead that vibrations in most cases enhanced the experience. When they later on performed the “Burn the controller” task, they did not associate the vibration as negative like those that performed that interaction first did.

Having only one kind of feedback raised different impressions for both cases. On the other hand, having them together did not create any associated feeling with the given feedback. Although their whole impression could be good for these participants, their comments were more directed towards design choices rather than to the interactions themselves. They often wished to have either the sound or the vibrations designed differently, and most often for the active feedback. If the vibrations did not align with the played sound and vice versa, it created an irritation and were more annoying than enhancing the experience. The reason why there was a difference between the individual and the combined cases is that when they performed the combined case, they had two given feedback and a possibility to compare them. Those that only had one feedback did not have anything to compare it to.

5.3 Sensitivity of haptics
Those that did a case that involved vibrotactile feedback thought that the intensity of the vibrations was different depending on what interaction they performed. This was independent of if there were sound or not and can therefore be seen as a person-dependent factor since all feedback was designed to have the same intensity and amplitude on all interactions. Humans have five senses where hearing and sight are two of them. People’s hearing differs between individuals and as well as people’s sight. It can be both with higher and lower sensitivity [25, 35]. Based on the comments from the participants regarding the perceived difference for the vibrations, this can also be connected to the touch sense, the third human sense.

On the question: “Were there any interactions where you wanted some other feedback than the one you received?” one person, who performed the case with only sound, wanted directed vibrotactile feedback. The motivation was that the directed feedback could be responsive to the interactions that the person would perform in the VE. By hitting an object on the left side would create a vibration on the right side of the controller - the side of the controller that hit the object in the VE. The participant described the Nintendo HD Rumble that Nintendo has released, but the participant did not know that Nintendo has implemented this.

“If I hit the side of it, that my controller on the side gives an impulse back on me, a directed vibration on the side of my hand. [...] That it would have been more responsive to how you interact with objects” - Participant 20 [Translated]

5.4 Method Criticism
During the interviews a few participants started to talk about the visual effects that they either liked or missed in the VE instead of the vibrotactile and auditory feedback. That took away some of the focus from the factors the study targeted and therefore lowered the trustworthiness in their answers. This since when they started talking about the visual effects the study moderator was forced to try to change the discussion back to the auditory and vibrotactile feedbacks again, but without revealing that this was the focus of the study. The VE did not contain a lot of visual feedbacks and that could have affected the results. It would be easier to draw even more accurate conclusions if all interactions had some visual feedback or if no one had it. The only visual feedback that was implemented was that the fan and the magnet turned green when they were moved when they were picked up or dropped, and that the fan and the magnet turned green when they were picked up. This could have affected the results, and one way to make that differently is to on beforehand announce that they were not supposed to focus on the visuals.

The answers could also have been affected by the hardware Magic Leap since almost no one of the participants had tried the Magic Leap before. The impressions could therefore have come from the interactions themselves but could also be contaminated by the impressions a new hardware gives first time users. One could remove some of the hardware impressions by letting the participants first try out the environment, but it cannot be removed completely.

One factor that could have given more detailed data is if Likert scales were to have been used for the interactions. By letting the participants rate each interaction on a Likert scale would have given a better comparison between each interaction. Bringing up a value from the scales to
complement the interviews would have given clearer indicators on how the participants perceived the interactions and the corresponding feedback.

5.5 Future work
This study investigated how the awareness of different feedbacks depend on the type of interaction. The sounds were not related to the type of interactions, neither the vibrations. One extension from this is to investigate how the users would perceive the feedback if these were related to the interaction. If the bushes would emit a sound of leaves and the fire a sparkling sound.

Since this study was made on a small test group with a narrow age range, this could be extended to involve a bigger variation of people with different backgrounds and wider age span. It can also be extended to other platforms such as a VR environment to see if there are any differences between an AR environment and a VR environment. HMD AR and VR often use the same interaction methods, but the visuals are different. This study focused on see-through HMD i.e. the participants could see the room they were in. If they were not able to see it, that could have affected how they perceived the different feedbacks.

6 CONCLUSION
The research question for this study was: What are the user experience differences between auditory feedback and vibrotactile feedback in a virtual environment and how can you design with auditory and vibrotactile feedback to enhance the interactions?

The results presented in this study indicate that vibrotactile feedback given by itself have a bigger impact to create different impressions when the user is interacting than with only auditory feedback. The vibrations could give both positive and negative impressions depending on what the earlier experiences were. If you start with an interaction connected to a negative action, the other interactions became connected to that impression since the vibrations were identical. On the other hand, auditory feedback by itself gave a feeling of being more natural and faithful but also easier to ignore and miss than the vibrotactile feedback. Given both feedbacks at the same time decreased the amount of noticed feedbacks compared to having only one feedback.

Passive interactions were indicated to be more noticed independent on what feedback that were given, while it was easier to miss the connected feedback for active interactions. Having auditory and vibrotactile feedback on passive interactions are not as common as visual feedback and adding feedback to these interactions could create a stronger sense of presence.

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REFERENCES


