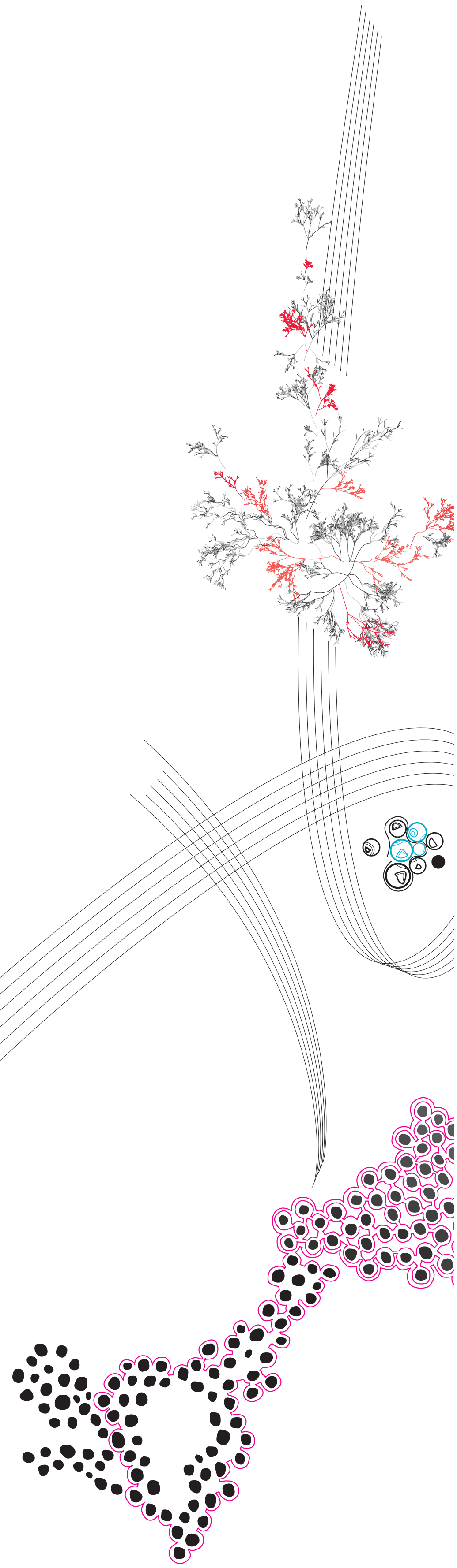
BSc Thesis Creative Technology



Influence of Cross-Modality on the Cutaneous Rabbit Effect

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Abstract

The Cutaneous Rabbit Effect (CRE) is a haptic illusion. This illusion is created by multiple taps at the elbow, followed by a tap at the wrist, which results in feeling like a tiny rabbit is travelling from the elbow to the wrist. The illusion can be perceived differently when visuals are added. This research aims to discover how an Augmented Reality (AR) visual can influence the CRE.

A vibrotactile sleeve with two vibration motors is used to create the haptic pattern of the CRE. This haptic pattern consists of three bursts at the elbow and one burst at the wrists. The duration between these bursts are equal and are called Inter-Burst Intervals (IBI). To visualise the CRE, a Blender model of a crow is animated on the arm. Arm tracking in AR is done by tracking the hands and calculating the points on the arm where the crow needs to land the jumps.

The results show that the experience of the CRE can be influenced by adding an AR visual. Five different speeds (25, 38, 52, 60, 98ms) were analysed. A sequence with an IBI of 52ms seems to create the illusion of the CRE the best when there are only haptics. When visuals get added, the IBI of 98ms gets the most influenced, as the other speeds are visually too quick to comprehend for the human brain. Findings suggest that when the visuals are sped up, the illusion vanishes immediately. The visuals can be slowed down with a maximum IBI of 100ms before the illusion starts to fade.

These findings can be affected by the difference in haptic and visual experience of people, human errors, limitations in documenting options or displacement of the sleeve. For future research, it is recommended to improve body tracking, explore the effect of a sliding haptic pattern and slow down the sequence more.

Keywords: Cutaneous Rabbit Effect (CRE), Augmented Reality (AR), Cross-Modal Illusion, Multi-Modal, Multi-Sensory

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1 Introduction

Humans use a combination of modalities to perceive events, but most do not realise how these cross-modalities are intertwined. In this day and age, people are used to working with mobile devices and computer systems. These systems rely on visual and auditory input for humans. Lazaro *et al.* [9] found that cross-modality causes a more natural, robust and flexible interaction between humans and computer systems. The impact of combining haptic feedback with computer systems is not fully explored yet. This haptic feedback could, for instance, be used to make a gaming experience or online communication with a loved one more immersive.

This research aims to gain insight into how to incorporate haptic feedback with computer systems. Exploration of this topic will be done by adding visual feedback to the haptic feedback of the Cutaneous Rabbit Effect (CRE). The haptic feedback of the CRE is a sequence of fast taps at the elbow followed by taps at the wrist. This sequence can cause the illusion of taps going from the elbow to the wrist as if a tiny rabbit hops down the arm. By adding a visual to the CRE, the haptic illusion becomes a cross-modal illusion. Tranquada-Torres *et al.* [18] found that the perception of an auditory illusion can be changed once visuals are added. Previous research ([1],[21]) shows that the haptic experience of the CRE can be influenced by visual feedback. Nevertheless, there has been no exploration yet into the influence of an Augmented Reality (AR) visual on the CRE.

Therefore, the main objective of this research is to discover how an AR visual affects the haptic experience of the CRE. This thesis will first explore how cross-modalities are linked and what aspects can influence a cross-modal illusion. Then, the impact of realism on an AR experience will be explored, as well as the optimal design space for the visual and haptic input of the CRE. The research questions will be discussed first, to give an overview of all the topics which will be explored.

1.1 Research Questions

The main question that will be discussed in this thesis is: "How does an AR visual affect the haptic experience of the CRE?" To get an understanding of this topic, there will be a literary exploration of what cross-modal experiences are. This exploration will dive into four subjects;

1. How are different types of input modalities connected?
2. What aspects affect a cross-modal experience?
3. Which cross-modal illusions are explored?
4. How did cross-modalities, which were previously applied to the CRE, affect the illusion?

After the topic of cross-modality is covered, exploration will continue onto how an experiment that incorporates an AR visual in the CRE is designed. This will be done by means of ideation, implementation and experimentation of an AR visual accompanied by the CRE from a haptic sleeve. Three main topics arise from this exploration;

1. Does realism have an impact on an AR experience?
    1.1 What aspects are important for making an AR visual realistic?
2. What haptic patterns are needed to create the CRE?

2.1 What is the optimal timing for the CRE?

2.2 What is the difference in the experience of the CRE when using a hopping versus a continuous pattern?

3. What is the design space for visual and haptic input for the CRE?

3.1 What is the optimal timing for the AR visual?

3.2 What is the effect of the AR visual not being congruent with the CRE?

2 Background Research

The inputs of modalities are connected, as we often link what we see to what we feel, what we hear to what we see, what we taste to what we feel, etcetera. Presley [12] states that the most common modalities, better known as senses, are touch (haptic or tactile), taste, vision and hearing (auditory). Combining these modalities is essential for human experiences, even from a young age. Robinson and Sloutsky [13] found that children benefit from cross-modal learning when the information they are studying can be used in multiple modalities, like rhythm and rate. Over time, humans have learnt to read, write, speak, and an important part of this is using multiple modalities to evaluate their perception of an event. A literature review was conducted to gain insights into the first sub-research question: 'What is a cross-modal experience?'. This chapter will first dive into two main speculations on how input modalities are interconnected, whereafter the most important impacting aspects of cross-modal experiences are analysed. Followed by an explanation of what cross-modal illusions are, how they occur and some well-known examples of cross-modal illusions. After that, a specific haptic illusion, the Cutaneous Rabbit Effect (CRE), will be explored, as well as the cross-modal influence on this illusion.

2.0.1 Connection between modalities

Cross-modal experiences happen when two or more modal inputs are used. There is no clear answer on how these modalities are interconnected, but there are two main speculations. Volcic *et al.* [20] state that all modalities have a reference frame, and once a modality gets input, this input is encoded in its own reference frame first. The first hypothesis Volcic *et al.* [20] introduce is that of a translation process for the encoded input, where either the input goes from one modality to the other or the input goes from multiple modalities into a multimodal format. This hypothesis is supported by Sathian and Lacey [15] and by Cinel *et al.* [3], who both claim that there is a multimodal integration of the encoded input in perception. Cinel *et al.* [3] state that the lack of attention can cause a misattribution of modalities. This implies that the encoded input is no longer connected to its original input modality. The nature of the task can impact which of the modalities becomes dominant, as remarked by Cinel *et al.* [3]. Sathian and Lacey [15] support this, explaining that vision is dominant over touch for shape recognition, whereas, for texture recognition, touch is the dominant modality. Ernst and Bülthoff [7] call this hypothesis the strategy of 'sensory integration', which they explain as the connection between redundant input modalities. The second hypothesis introduced by Volcic *et al.* [20] is a direct comparison of the encoded input between multiple modalities, also mentioned by Ernst and Bülthoff [7] as 'sensory combination'. This claim is supported by O'Callaghan [11] who remarks that perceptual organising strategies, which are adaptive and therefore easily influenced, are used and that cross-modal illusions can result from these organising strategies. Modalities are thus connected either by passing on encoded input between modalities (sensory integration) or by comparing the input between modalities (sensory combination).

2.0.2 Affecting Aspects of Cross-Modalities

Cross-modal experiences can be influenced to become an illusion. To go more into depth on how Cross-Modal experiences work, the three most affecting aspects will be explored. Roseboom *et al.* [14] researched affecting aspects of a cross-modal illusion, the Double Flash Illusion (DFI), and discovered that the most important aspect is a featural similarity of the input signals. This conclusion arose from an experiment where it was found that the illusion did not work when different types of input modalities were used. Prinzmetal (as cited in [3]) confirms this by stating that illusions are more prone to happen between stimuli which are grouped, instead of non-grouped stimuli. Cinel *et al.* [3] found that failure to connect the inputs across modalities is a cause for faults in cross-modal experiences, which supports Prinzmetal's claim that grouped stimuli help to enhance a cross-modal experience. The next important aspect, discussed by Roseboom *et al.* [14], is the influence of spatial aspects on input signals. Roseboom *et al.* [14] mention that to make the DFI work, the inputs should come from a common place of origin, which indicates that source determination plays a role. Influence of spatial aspects is also seen with the Kappa effect, studied by De Pra *et al.* [4], which is an illusion where the time between two consecutive stimuli feels longer when the distance between the origin of these stimuli is larger. Therefore, De Pra *et al.* [4] state that temporal and spatial aspects are interconnected. The opposite of the Kappa effect is the Tau effect, studied by Kawabe *et al.* [8], who found that the spatial interval of flashes was experienced as shorter when the timing between three consecutive tones was shorter. The Tau effect suggests that temporal aspects are the third important influence on cross-modal experiences. This is supported by the study of Volcic *et al.* [20], which concluded that the awareness of one's body in space was influenced by temporal delay. Intertwined with this finding is the finding of Roseboom *et al.* [14] as well as Soto-Faraco and Alsius [17], who concluded that attention influences the connection between modalities. Soto-Faraco and Alsius [17] discovered this, as the cross-modal illusion that they were studying, the McGurk illusion, became less impactful in the case of a high attention load. Leading to the conclusion that the connection between modalities can be influenced by featural, spatial and temporal aspects. These three aspects include influences of grouped stimuli, source determination and attention span.

2.0.3 Cross-Modal Illusions

The featural, spatial and temporal aspects can influence a cross-modal experience in such a way that it becomes an illusion. Next to the Kappa and Tau effect, there are three cross-modal illusions which are often studied by researchers. Soto-Faraco and Alsius [17] studied the McGurk illusion, an audiovisual illusion where a sound, for example, 'ba', is simultaneously played with a video which shows lips displaying a different sound, for example 'ga'. In this case, the visual will influence the auditory input, as the observer hears either the sound displayed by the video or a combination of the auditory and visual input. In the case of 'ba' and 'ga', this would result in hearing 'da'. A different example of visual input affecting auditory input is the study of Tranquada-Torres *et al.* [18], who studied the influence of cross-modality on the tritone paradox. The tritone paradox is an auditory illusion where, once two consecutive tones are heard, they can be heard either ascending or descending in pitch. Tranquada-Torres *et al.* [18] observed that by adding a visual of a music bar, the tones were heard as descending when the notes were displayed as descending and vice versa for ascending. This effect had a bigger impact on musicians than on non-musicians, as musicians are more experienced with reading music bars. An interesting finding of Tranquada-Torres *et al.* [18] is that the tritone paradox was also influenced unconsciously by the visual, meaning the participants did not know the visual input was causing them to experience the auditory input differently. In these two examples, the visual input was dominant, but an example of an audiovisual illusion where the auditory input is dominant is the Double Flash illusion, studied by Roseboom *et al.* [14]. This is an illusion where one flash of light is perceived as two flashes when two beeps are heard. By studying this illusion, Roseboom *et al.* [14] concluded that the featural similarity of modalities is important to cause the illusion. Looking at these three examples of cross-modal illusions, it stands out that they are all audiovisual, which means that audio and visual input modalities are quite well aligned. Visual and auditory input can both be dominant for cross-modal illusions, which supports the statement that the dominance of modalities depends on the task at hand. It seems that cross-modality has a positive influence on illusions, as it can enhance the experience. Using Virtual Reality (VR) or Augmented Reality (AR) can boost immersion in an experience, according to De Pra *et al.* [5]. Lazaro *et al.* [9] support this, as they found that cross-modality causes a more natural, robust and flexible interaction between humans and computer systems, but they also argue that cross-modality can lead to a higher mental demand and can therefore cause errors. Lazaro *et al.* [9] found that an audiovisual experience was easier to apprehend when it was non-verbal, as a verbal audiovisual experience took more mental and temporal demands.

2.0.4 Conclusion of background research

The background research aims to discover how input modalities are interconnected and how this connection is experienced. Once modalities get input, they will either pass it on to another modality or compare the input between modalities. It is uncertain which of these hypotheses is true, but the hypothesis of translation across modalities seems to be more common among researchers. There are three aspects which are most likely to influence a cross-modal experience: featural aspects (grouped stimuli), spatial aspects (source determination) and temporal aspects (attention span). These three aspects can cause a cross-modal experience to become an illusion. A few common cross-modal illusions are the McGurk illusion, the cross-modal influence on the tritone paradox and the Double Flash Illusion. These are all audiovisual illusions, whereas in the case of the Double Flash Illusion, audio is the dominant modality, whereas with the other illusions, vision is dominant. This shows that the dominant modality can vary per cross-modal experience. VR and AR seem to be a great way to enhance a cross-modal illusion as they boost immersion in an experience.

2.1 Related Work

Research on cross-modalities has been done before, but more recently, this research has delved more into the topic of cross-modal integration with computer systems. Related works have been studied to see which findings have already been made, as well as to discover recommendations for future studies. This chapter will describe six studies, starting with a study on multimodal interaction on AR, followed by a study on perceived softness using haptic feedback and a VR visual and then a few studies which are more focused on the CRE.

2.1.1 Multimodal interaction: Input-output modality combinations for identification tasks in augmented reality

Lazaro *et al.* [9] found from their literature review that cross-modal interaction can cause a more natural and flexible interaction with computer systems, but that it can also lead to cognitive overload, which leaves room for error in perception or functioning. To dive deeper into this topic, they studied how humans respond to different combinations of input and output modalities. An example is given in Figure 1, which shows the output modalities of the AR headset. Lazaro *et al.* [9] found that the input and the output modalities are dependent on each other. They also found that non-verbal visual and auditory input results in a shorter task completion time and less mental demand, as opposed to verbal input. A potential cause of this is that verbal information takes up more mental processing load.

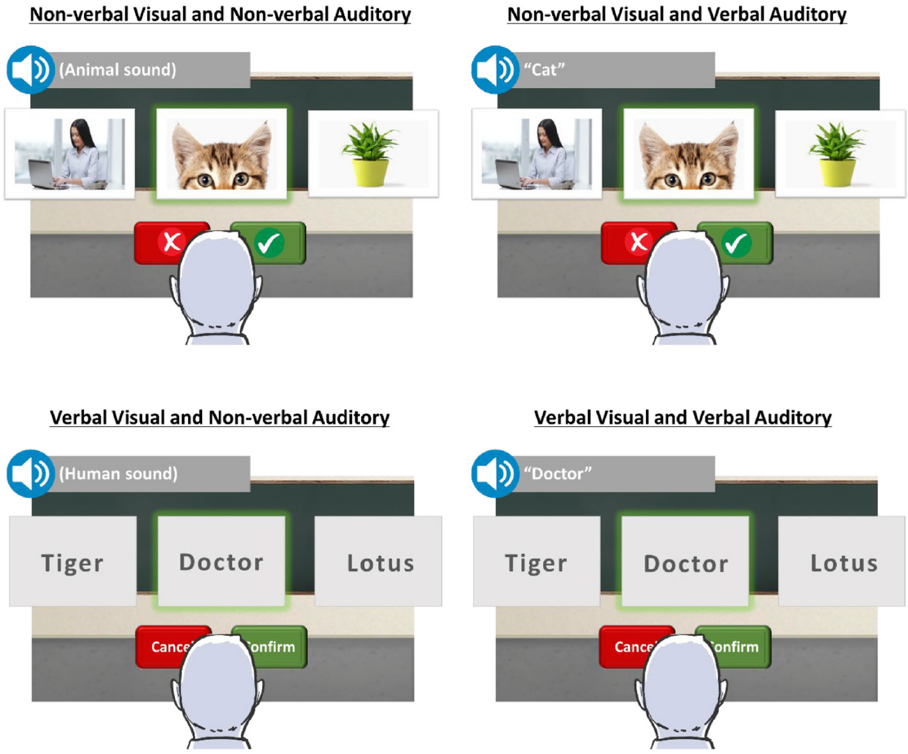

FIGURE 1: Multimodal interaction testing in AR by Lazaro *et al.* [9]

2.1.2 Augmenting Perceived Softness of Haptic Proxy Objects Through Transient Vibration and Visuo-Haptic Illusion in Virtual Reality

Choi *et al.* [2] investigated the perception of softness with a visuo-haptic illusion. To create this illusion, they used a VR visual in combination with a handheld device, which can be pressed, causing the device to vibrate (see Figure 2). They found that this device was able to influence the perceived softness by means of vibration, this effect even works when the device is tapping on a hard surface. Testing with both the VR visual and the device resulted in an even more immersive experience. It was noticed that the VR visual had a bigger impact on the perceived softness as opposed to the vibrations from the handheld device. Testing only with the VR visual, confused perception and made participants rely more on the visual.

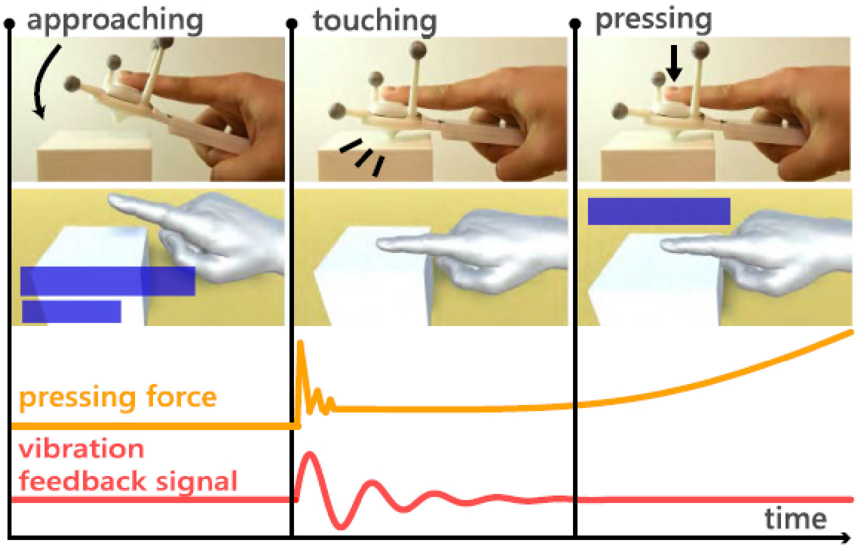

FIGURE 2: Handheld device used for recreating softness, created by Choi *et al.* [2]

2.1.3 Cutaneous Rabbit Hopping out of the body

Miyazaki *et al.* [10] stated that haptic perception does not always align with the location of the haptic stimuli. Therefore, they investigated whether this is possible with haptic perception on an extension of the body. Participants of the study held a flat stick at the tips of their index fingers and closed their eyes as two sets of piezoelectric contactor systems delivered pulses to the index fingers. First one pulse on one finger, and after a delay of 800ms the second pulse on the same finger, followed by another pulse on the other finger after 50ms or 80ms. The participants used a pointer set (see figure 3c) to indicate where they felt haptic feedback. From their indications, it followed that the second pulse was experienced to be somewhere in the middle of the stick, which confirms Miyazaki's *et al.* [10] hypothesis that the CRE can take place outside of the body. This means that the brain can include an object, like the stick, in the body perception.

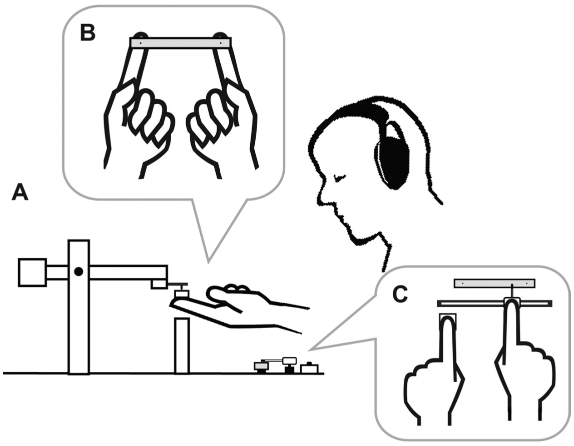

FIGURE 3: User test set up of Miyazaki *et al.* [10]

2.1.4 Snake Effect: A Novel Haptic Illusion

Two well-known illusions of movement are sensory saltation, like the CRE, and tactile apparent movement. The difference between these two is that sensory saltation feels like something hopping up the forearm, while tactile apparent movement feels more like something is sliding across the skin. Severgini *et al.* [16] studied this tactile apparent movement and called it 'The Snake Effect', which they describe as "a continuous and oscillatory movement illusion" (p. 908). To create the Snake effect they made a sleeve (see Figure 4), consisting of six pairs of actors (Figure 4a) a protective sleeve (Figure 4b) and the fastening was done by Velcro strips. The tactors were driven by an audio signal from a MOTU 24Ao device, which got input from a MATLAB program.

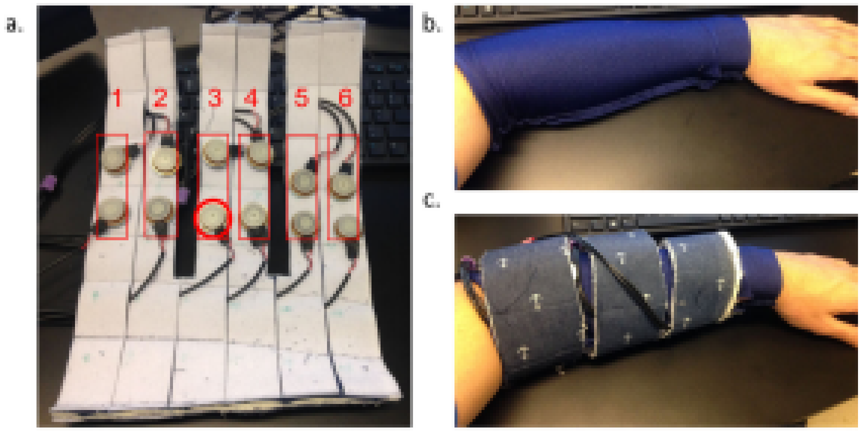

FIGURE 4: Set Up of the Snake Effect Experiment by Severgini *et al.* [16]

Severgini *et al.* [16] found that participants felt a continuous movement along their arm when amplitude modulation (either sine, sine-squared or Gaussian waveform) was applied to the tactors, even though the tactors are placed in separate locations. The Snake effect takes longer to produce, a minimum of 1.69 seconds is needed, as opposed to the CRE. One of the reasons for this is that a snake's movement is slower than that of a rabbit, so slower haptic feedback enhances the immersiveness of the snake effect.

2.1.5 Emotional dimensions of the CRE in VR

Ziat *et al.* [21] used a VR animation of multiple animals (rabbit, spider, kangaroo, flea, frog) and a sphere (as a neutral stimulus) in combination with the haptic feedback of the CRE to discover which kind of emotions arose with the participants. For the VR setup, they used the Unity game engine for the visuals and a Meta Quest Pro headset. The haptic illusion was created by a sleeve with three C2 actuators, spaced 5 centimetres in between them. Figure 5 shows the position of these actuators, P1, P2 and P3. Next to that, it shows that three bursts will be given to the actuators with an equal inter-burst interval (IBI) to create the CRE. Ziat *et al.* found that the optimal length of the IBI is 24 milliseconds. To avoid delay issues between the visual and haptic feedback, ASIO4ALL was used by creating a sound transmission which drives the actuators. Ziat *et al.* [21] found that the type of animal and the number of visual hops, three or nine, influenced the participants' emotions. This was seen as the participants felt happier when seeing the kangaroo, rabbit and sphere, while they felt neutral towards the frog and negative towards the spider and flea. When seeing the flea hop nine times, participants would feel calmer than when seeing it hop three times. This is probably also due to the flea's size. Overall, participants did think that the combination of visual and haptic feedback added to the feeling of realism. It was noticed that testing with multiple animals of different weights seems to be unrealistic when the intensity of the vibrations of the actuators is the same, as it should be more intense for heavier animals.

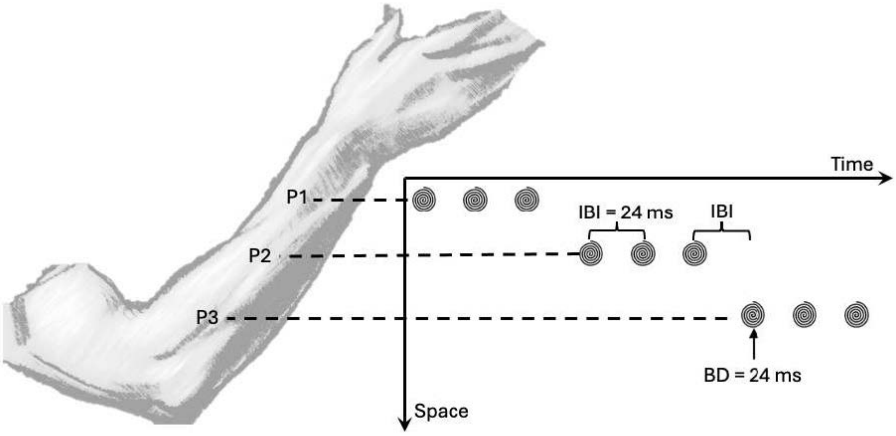

FIGURE 5: Haptic pattern used by Ziat *et al.* [21] to create the CRE

2.1.6 Designing a VR application as cross-modal extension of the Cutaneous rabbit effect

This Bachelor's thesis for Creative Technology of de Zwaan [6] is inspired by Ziat *et al.* [21]. De Zwaan focuses more on whether the VR visual affects the haptic feedback of the CRE. For this, she used a visual of a crow hopping along the arm. As de Zwaan's project was the basis of this thesis, more information on the specification can be found in chapter 4. The set-up of de Zwaan's experiment can be seen in Figure 6. De Zwaan [6] found that the CRE was felt over multiple speeds, with the IBI varying from 25ms to 98ms. Although at an IBI of 98ms only half of the participants felt the illusion. Adding the visual resulted in that, with an IBI of 98ms, most participants did feel the illusion, while with an IBI of 25ms only half of the participants felt the illusion. The speed of animation needs to be better calibrated to match the CRE of the vibrotactile sleeve. The model of the arm tends to be disruptive, as it is quite large and just floating around in space. De Zwaan [6] recommends using an AR environment to make the experience feel more realistic. Other recommendations include investigating if a sliding effect will enhance the illusion more than a hopping effect, as well as using stronger vibration motors, as the ones which were currently used disturbed the synchronisation of the visual and haptic feedback.

FIGURE 6: Set up of de Zwaan's [6] VR visual and vibrotactile sleeve

2.1.7 Important takeaways from related work

It is shown that cross-modal interactions make the interactions with computer systems more immersive, this can be achieved by combining VR or AR visuals with haptic feedback from vibration motors. Synchronisation of the visual and haptic feedback is important, especially when the IBI is higher. Most of these devices use an audio driver, like ASIO4ALL, for synchronisation. For testing such devices, it is useful to have a physical indicator to show where the participant noticed that the haptic feedback was given. It should also be taken into account that the type of animal and the amount of hops they take influence the experience. In case testing includes multiple animals, the intensity of the vibrations should be scaled to the supposed weight of the animals. It is hypothesised that an AR visual would work better for immersing the user in the CRE, as with AR, the visual would appear on the user's arm instead of a modelled one. Another suggestion is to investigate the difference between the hopping sensation of the CRE and the sliding sensation of the snake effect.

3 Ideation

The ideation started by creating a list of preliminary requirements. Based on these requirements, a mind map was created to start the concept generation. Further concept generation was done by means of idea sketching. These ideas are evaluated by an expert interview with Mounia Ziat.

3.1 List of preliminary requirements

The list of preliminary requirements (see Table 1) was made by all the information gathered from the background research and suggestions from related work. Besides that, the technique of translating values into design requirements from Van de Poel [19] was used to take some ethical values into consideration (see chapter 3.1.1).

No.	Requirement	Source
1	Vibration motors must deliver taps at consistent intervals	Background research and Values to design requirements
2	There must not be a delay between the visual and haptic input	Related work 2.1.6 and Values to design requirements
3	The experiment should not take too long	Values to design requirements
4	The AR should not show anything more than the visual needed for the CRE.	Values to design requirements
5	The experiment needs to take place in a quiet, neutral room with no distractions	Values to design requirements
6	The participant can stop the experiment at any time they want	Values to design requirements
7	The participant needs to have an indicator for the haptic feedback	Related work 2.1.3
8	The device must be light	Related work 2.1.5, 2.1.6
9	The device must be adjustable according to different arm sizes	Related work 2.1.4, 2.1.5,2.1.6
10	Intensity of vibrations must be scaled to the weight of animals	Related work 2.1.5
11	There should be a big sample size of user tests	Related work 2.1.6

Table 1: Design requirements

3.1.1 Translating values into design requirements

Van de Poel specifies three layers of a values hierarchy in his paper 'Translating Values into Design Requirements': Values, norms and design requirements [19]. These layers are used to create design requirements, keeping in mind some ethical considerations.

Values are used to describe important aspects that reflect the strength and validity of the research, according to Van de Poel [19]. There are three important values regarding implementing an AR visual with haptic input of the CRE. The first one is accessibility, as it is important to make sure the application can be used by all kinds of participants. The second value is safety, as the device should not cause any harm or be uncomfortable to use. The last value is reliability because the device should work properly for all participants during all experiments.

Norms are described by Van de Poel as guidelines and limitations of the actions of the research [19]. There are three important norms. The first norm is that the device should have accurate timing and congruency because the haptic and visual stimuli must be timed simultaneously in order to get sufficient results. Besides that, the device should cause minimal cognitive overload, as the design should be as simple as possible so that there are no distractions from the haptic or visual stimuli. Lastly, the experiment should prevent motion sickness and headaches, as this can be caused by AR headsets when they are used for a long period of time.

Design requirements are according to Van de Poel created from the Norms. These requirements are more specific and measurable than the Norms [19]. When looking at accurate timing and congruency, some important design requirements are: the vibration motors must deliver taps at consistent intervals, and there must not be a delay between the visual and haptic input. Looking at the next norm, minimal cognitive overload, three design requirements arise. The first one is that the experiment should not take too long. Besides that, AR should not show anything more than the visual needed for the CRE. Lastly, the experiment needs to take place in a quiet, neutral room with no distractions. Considering the prevention of motion sickness and headaches norm two design requirements stand out; the experiment should not take too long, and the participant should be able to stop the experiment at any time they want.

3.2 Concept generation

To start the concept generation, a mind map was created (see Figure 7). This mind map gives an overview of some preliminary requirements, suggestions from related work and associated aspects of these. Five main topics were found: AR implementation, timing, single modality compared to cross-modality, continuous compared to hopping haptic pattern and user tests.

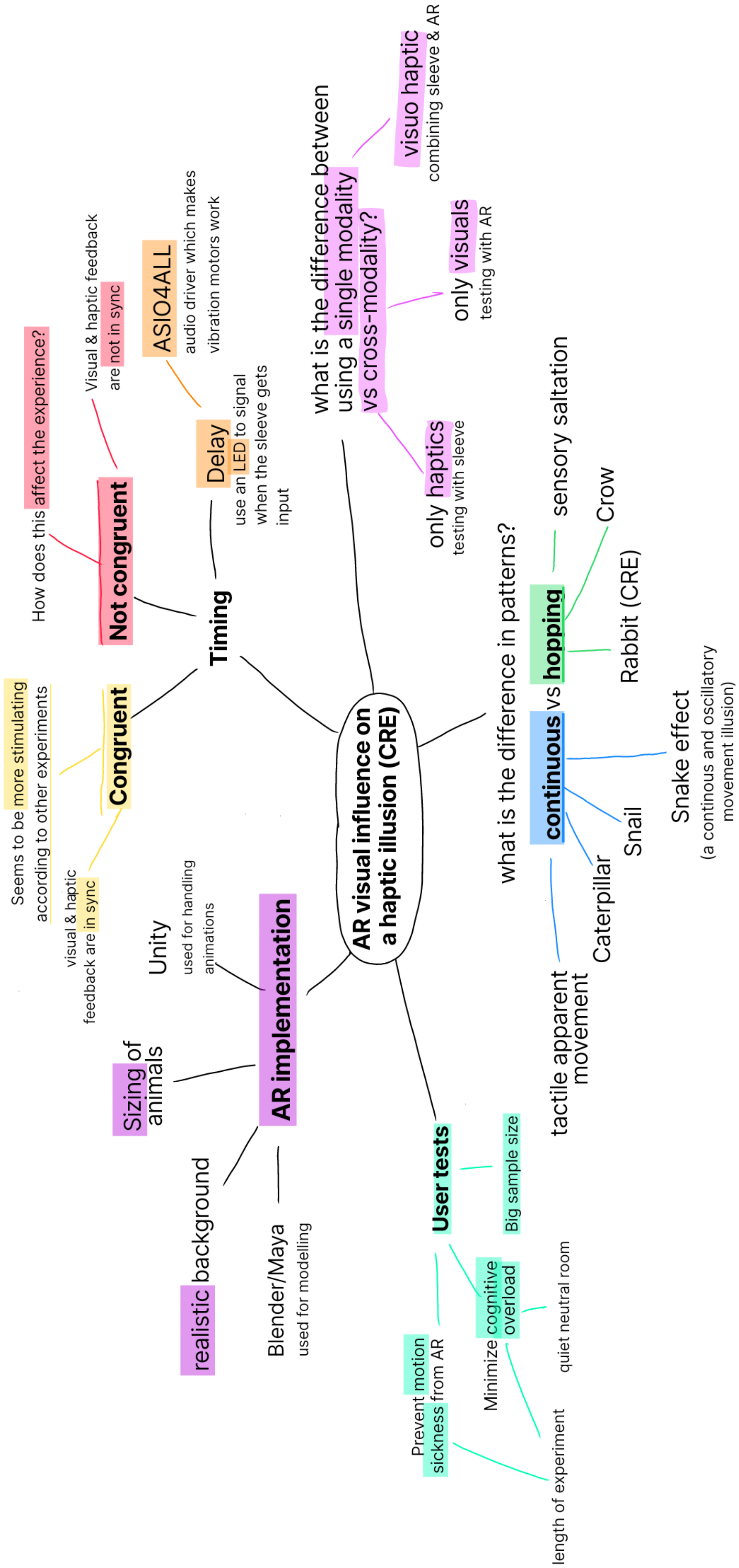

Figure 7: Mind map for concept generation

3.2.1 LED implementation for delay

The timing of haptic and visual feedback is important for making the CRE work. De Zwaan 6 found that there is a delay at the start of the AR visual and a delay at the start of the haptic feedback. These delays are not the same, causing the visuals and haptics to appear at different timings, which makes the CRE less realistic. The Unity program can be started by pressing the space bar, whereafter the visual is sent to the AR headset. Simultaneously, a start signal is sent to the Arduino to make the motors in the sleeve vibrate. This signal is sent by means of ASIO4ALL, as this will send a low-latency audio signal. In order to discover the delay between the haptic and visual feedback, an LED will be implemented in the Arduino system. By filming this LED and the visual simultaneously, the difference in delays can be measured. After analysing the delays, a plan of action can be made to eliminate these delays.

3.2.2 Sliding Character Ideation

The research of de Zwaan [6] used a crow visual hopping along an arm. Comparing a hopping and a sliding haptic motion means that another visual will have to be created to present the sliding effect. As a crow is not able to slide, multiple animals, who move with a sliding motion, have been considered and sketched for visualisation (see Figure 8). A snake (Figure 8A) can be modelled in a realistic size, but a challenge would be that a snake moves in a swivelling motion, which could be too hard to match with the haptic pattern. Other creatures which can be modelled in a realistic size are a caterpillar (Figure 8B) and a snail (Figure 8C). Opposed to the snake, these two creatures move in a straight sliding motion. Even though a snake, caterpillar and snail are great options for making the visual realistic, they are not the most pleasant animals to have on your arm. This can cause participants to get uncomfortable during the experiment, resulting in them having to stop the experiment early. Leading eventually to the result being insufficient. Animals which would be less realistic to have to slide along your arm could be a seal (Figure 8D), a penguin (Figure 8E) and a squid (Figure 8F). These are less realistic as humans do not interact with them often, and the size of the seal and penguin needs to be smaller than in real life. Concluding that a choice has to be made between an animal which is realistic but uncomfortable to have sliding along your arm, or an animal which is more comfortable but less realistic.

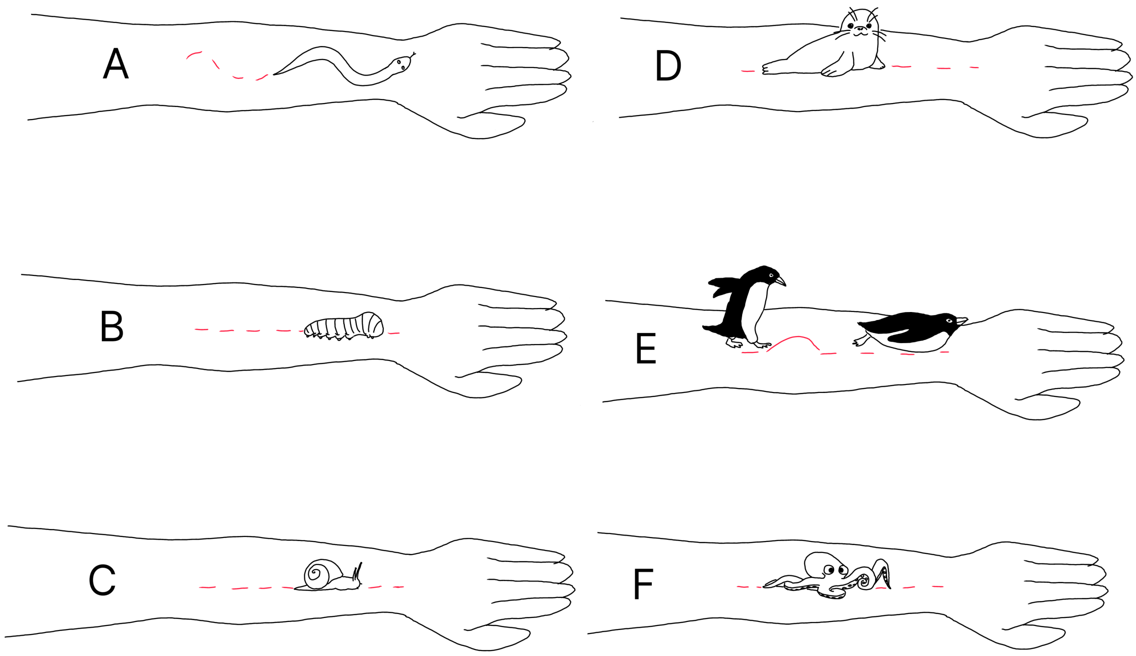

FIGURE 8: Sketches for possible animals for sliding effect

3.3 Expert insights: an interview with Dr. Mounia Ziat

To incorporate an expert opinion on the ideation, an interview with Dr. Mounia Ziat was conducted. Ziat has a PhD in cognitive science and has undertaken multiple studies on the CRE and visual influence on the CRE. One study, which is described in the Related Work (see 2.1.5), is the foundation for this paper. Therefore, it is important to incorporate her views on the topic in this research. Dr. Angelika Mader, of the University of Twente, also took part in this interview, as she gained a lot of knowledge on this topic through related studies, and she is experienced with the previous study done by de Zwaan [6]. From this interview, three important topics arose: the immersiveness of AR, the timing of the haptic and visual feedback and the implementation of animals in the visual. Pieces of advice from Ziat are to use AR to boost immersiveness, play around with the timing of the CRE, as well as to play around with the sizes of the animal visuals. These three topics will be discussed in the upcoming paragraphs.

3.3.1 Immersiveness of Augmented Reality

Ziat has done multiple experiments regarding the visual influence on the CRE, ranging from 2D pictures projected on an arm to VR visuals. Testing with 2D pictures caused a dissociation between the location of tactile and visual stimuli; therefore, the experience was not immersive enough. Experimenting with VR boosted the immersiveness, but a disadvantage of VR is that an arm needs to be visualised. As the modelled arm is not the same as the user's arm, as it can vary in gender and skin colour, this can cause a dissociation for the user. Ziat believes that implementing AR could boost immersiveness even further because the user will be able to see their arm and move it around. One thing that does need to be taken into account is that with AR, the user will also be able to see the vibrotactile sleeve. Ziat and Mader both agree that when combining a visual with the CRE, a lousy haptic pattern can play the trick. Ziat does mention that this is mostly the case for negative situations. In case the user sees a pleasant visual, like a loved one touching their arm, they will be more picky on how accurate the haptic pattern is, because if it is not accurate, they will feel more dissociation. Mader adds to this with knowledge of a previous study, in which a visual of a bartender was used. In case the interaction with the bartender was negative, the haptic feedback would make this experience even more intense. Remarkably, the intensity of the experience would not be increased when the interaction with the bartender tended to be positive. This leads to the hypothesis that the implementation of AR will boost the immersiveness of the experience, but the accuracy of the haptic pattern will depend on how pleasant the AR visual is.

3.3.2 Timing

Ziat did not experience delays between the haptic and visual feedback, she mentions that this might be a consequence of having a fast pattern. She tested with an IBI of 24ms, causing the total sequence of 9 taps to be less than 500ms. Ziat states that the short sequence might explain why the delay did not have any effect on the experience because if there was even any delay, the sequence would be too fast to notice. Mader adds that de Zwaan tested with longer intervals (maximum IBI of 98), which made the delay more noticeable and that this delay probably originates from an electronics problem. Ziat comments that for combining a visual with the haptic pattern, the CRE should indeed have longer intervals, as the tactile timing is too fast for the visual, causing the haptic illusion to be broken down by the visual. Ziat advises to play around with the timing and to determine how big the delay is. Depending on this delay, the haptics or visual feedback should be triggered later.

3.3.3 Animal implementation

Looking into a hopping versus sliding effect means that a new animal should be used as a visual with a sliding motion. Ziat has experience with testing on multiple animal visuals. From this, she noticed that the intensity of the vibrations should be scaled to the weight of the animal, otherwise users will feel disassociated. Besides that, the size of the animal is important to investigate. Ziat mentions she experimented with a visual of a type of Himalayan mountain goat, which was too unrealistic to see such a big animal hopping along your arm. Ziat advises testing with animals of relatively the same size. After seeing the sketches of possible sliding animals (see figure 8), Ziat explained that the penguin could be a good choice, as this animal can move in both hopping and sliding motions. Ultimately, the most important aspect of the animal will be its size to make the visual feel realistic.

4 Specification

4.1 Haptic feedback

The haptic feedback is given by a vibrotactile sleeve (see Figure 9 and 10). This sleeve consists of two vibration motors, which are controlled by an Arduino Nano. The pattern used to create the CRE is three vibrations at the elbow, followed by one at the wrist (see Figure 11). The time which passes between these vibrations is called the Inter-Burst Interval (IBI). At the start of the jumping sequence, Unity will send an audio signal to the Arduino to make the motors vibrate. ASIO4ALL is an audio driver which makes sure the signal gets sent with little to no latency. Having no latency is crucial to make sure the haptic and visual feedback are synchronised. To visualise the synchronicity, two LEDs are implemented. These LEDs will light up at the same time as the motors vibrate. A red LED is used for the motor near the elbow, and a green LED for the motor near the wrist. The potentiometer is able to control the speed of the jumping sequence. Appendix A shows an overview of how these parts are connected.

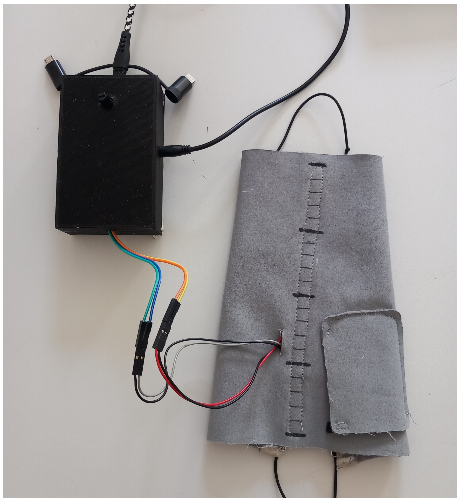

FIGURE 9: Front of the haptic sleeve

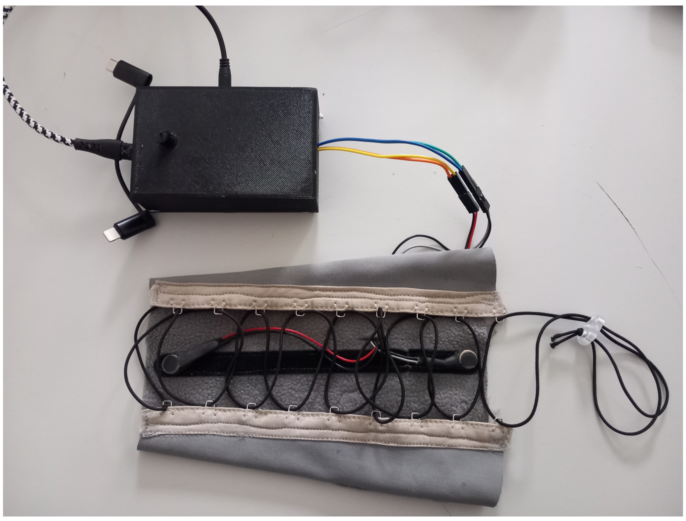

FIGURE 10: Back of the haptic sleeve

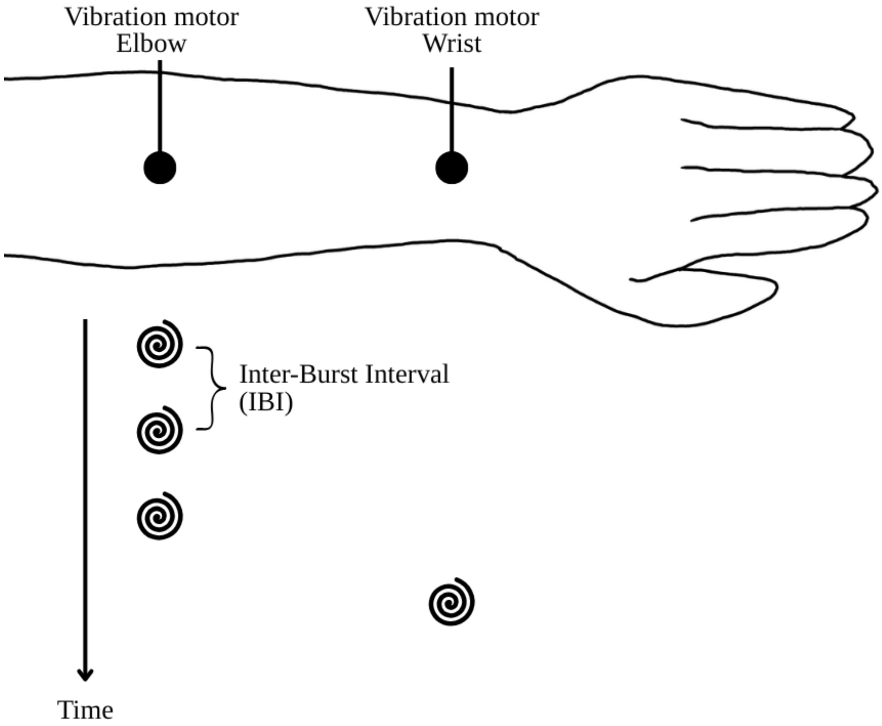

FIGURE 11: Haptic pattern given by the sleeve

4.2 Visual feedback

Unity controls the visual feedback and sends an audio signal to the Arduino. A Jump-Controller script takes care of the length, position and height of the jump. The model for the crow, made by de Zwaan [6], was created and animated in Blender. Due to time restrictions, the idea of using a sliding character was disregarded. A Meta Quest 3 headset is used to display the visuals. This headset was chosen because it is very beginner-friendly for working in Unity. Meta has created 'building blocks' for Unity, which are objects already including the scripts necessary to make an AR experience. Some examples of these building blocks are the camera rig, which takes on the position of the headset, passthrough, which makes the headset show the real world, and hand tracking.

5 Realisation

5.1 Resolving delay between visuals and haptics

The first tests for the delay were done with the largest IBI (98 ms), as the delay is quite small, so harder to see with a smaller IBI. The LEDS were filmed with the visual showing in the background. By putting these videos in a video-to-frame converter, approximately every 33.33 ms of the video could be evaluated. Figure 12 shows a comparison between the visual and haptic feedback. This figure is based on one video, as the delays were consistent; therefore, it is not needed to compare multiple videos. A flat line means that the bird is standing on the arm or that there is haptic feedback given. The bows represent the actual hop, so the bird is not on the arm, and there is no haptic feedback. There are four hops (A, B, C & D) which should be synchronised. As seen in figure 12 hops A and B are somewhat synchronised. It does seem that the visual cycle is faster, as the intervals between jumping and standing on the arm are not consistent with the haptic pattern. The values of the visual hops were evaluated, which led to finding flaws in the assigned values. After altering these values, the jump sequence for an IBI of 98 seems to be synchronised (see Figure 13).

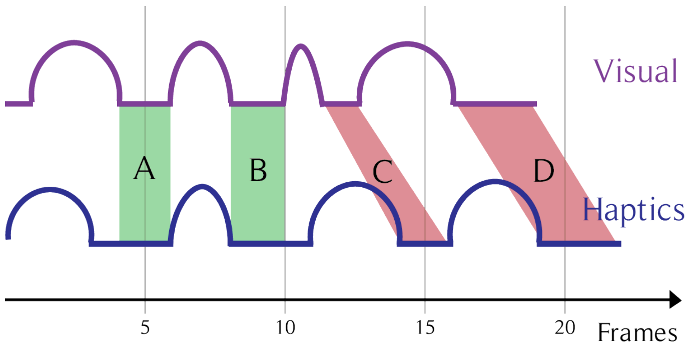

FIGURE 12: Visual and Haptic feedback delay compared

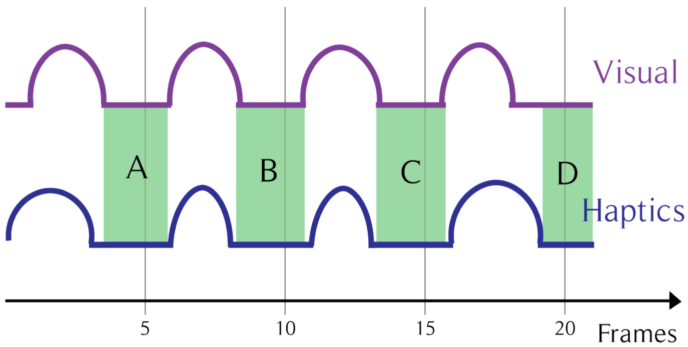

FIGURE 13: Synchronised Visual and Haptic feedback

Seeing that the visual and haptic feedback is now synchronised for an IBI of 98ms, it should also be evaluated if they are synchronised for other IBI's. For an IBI of 80ms, 60ms and 52ms the visuals and haptics are still completely synchronised. For an IBI of 38ms or 25ms, the haptic feedback seems to be one frame late. This latency could be explained by the fact that these sequences are too fast to capture accurately on video, even when splitting them up in frames. If there is a delay, it would be too short to notice, therefore, the IBI's of 38ms and 25ms are still considered to have synchronised feedback. In case there is no constant haptic feedback given, it is important to check if the volume of the laptop is set at a sufficient amount, as an audio signal makes the motors of the sleeve vibrate. The tests shown in figure 12 and 13 were done without the Meta Quest attached. However, when doing the same test with the Meta Quest, the visual and haptic feedback remained synchronised. Leading to the conclusion that the AR headset does not influence the delay. The importance of solving this delay seems to be assigning the right values to the visuals of the jumping sequence.

5.2 AR Implementation

The AR implementation was done by using the Meta XR All-in-one SDK package. This package handles the camera position, the passthrough for seeing the real world, and the connection to the headset. The all-in-one package is not able to do full body tracking, only hand, face and eye tracking. Therefore, the Meta movement SDK package is implemented to track the left arm. This package can animate a character in place of your real body and includes samples of such a character. This sample character was used to track the body. As there should not be a character arm in view, the character's materials were made transparent, making the character invisible. From the body rig, the elbow, middle of the arm and wrist positions can be found. The elbow and wrist positions were given an offset to make the placement more accurate. The positions between the elbow and the middle and between the middle and wrist were calculated, leading to five positions on the arm (see Figure 14). The position of the tip of the index finger is tracked as well so the animal faces the hand at all times.

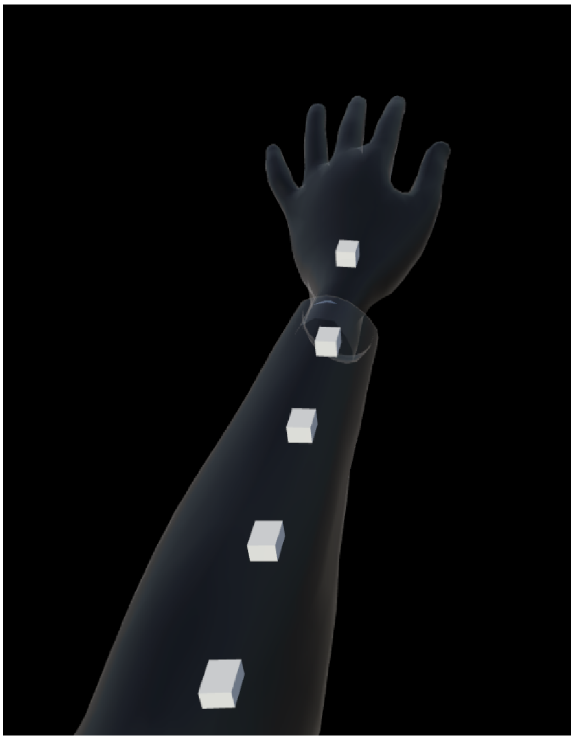

FIGURE 14: Jump positions visualised on the prefab's arm

5.3 Incongruency

To make the haptic and visual feedback incongruent, the visual feedback is sped up or slowed down. This is implemented in such a way that the researcher is able to set the animation with a decrease or increase in IBI. The researcher can also set the amount by which this increase or decrease happens. It is hypothesised that speeding up the animation can disturb the haptic feedback by quite a lot, while with a slowed-down animation, the visuals still seem to be realistic, together with the haptic feedback.

5.4 User test set up

During user tests, the participants are asked to point to the locations where they have felt haptic feedback. A scale has been drawn on the sleeve so the researcher is able to interpret these locations (see figure 9). The scale goes up to twenty, as these are approximately the number of locations a participant can point to on their forearm. Every five steps, there is a bigger marker to increase readability. The researcher can input the location information into a Processing script. Figure 15 shows an example of this script, where there are tick boxes for the speed of the haptics and an input box for the offset of the speed of the visuals (where s means the same speed). This script uses a grid with twenty columns, which resembles the scale on the haptic sleeve. There are twenty-five rows for time reference, and each five rows means one IBI. In the example, you can see that haptics (red dots) and visuals (blue dots) appear to happen at the same location, but that the visual sequence is half an IBI behind in timing. The locations of these dots are saved in a CSV file so they can be processed later on.

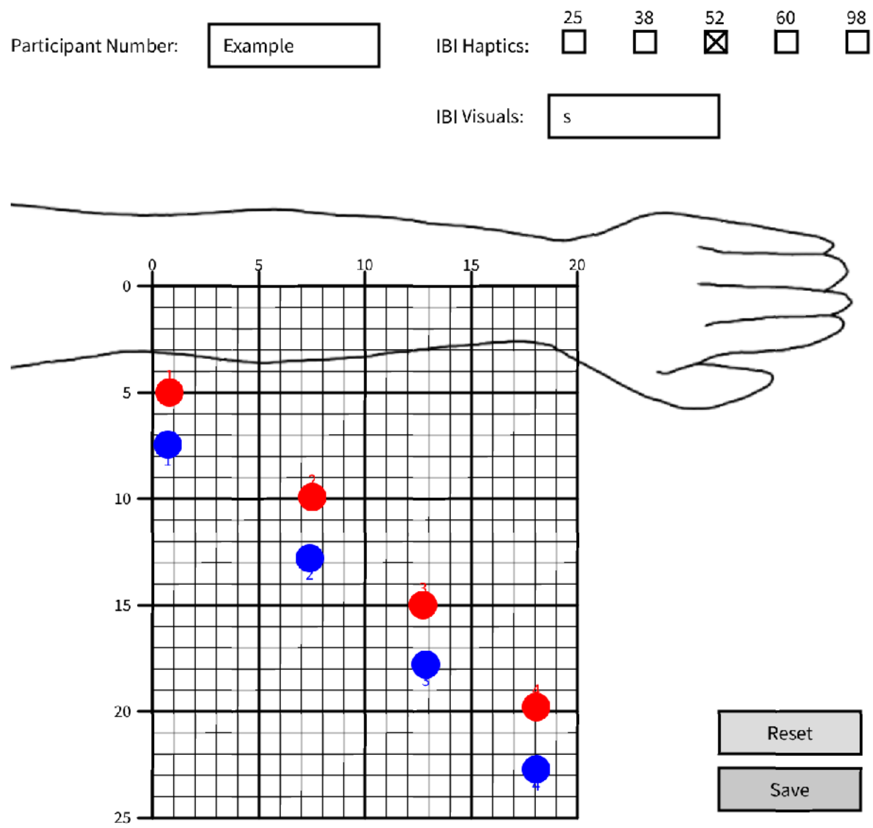

FIGURE 15: Processing input for user tests

The user test starts off with an explanation of the experiment, and the participant will be given an information letter (see Appendix E) and a consent form (see Appendix D). The researcher will put the haptic sleeve on the participant, after which the participant will be asked to point out where on the forearm they have felt haptic feedback. This will be done for five different speeds (25ms, 38ms, 52ms, 60ms, 98ms) selected in random order. The researcher uses a questionnaire (see Appendix F) where the random order can be filled in together with any additional comments from the participant. After testing with only haptic feedback, participants will get the AR headset put on and point again to the place where they felt haptic feedback, this time including visuals. The slowest speed (IBI of 98ms) is used to test how much delay the visual can have before the illusion of the CRE disappears. This is tested with delays of 25ms, 50ms, 75ms, 100ms and 150ms. Afterwards, the researcher will help the participant take off the AR headset and the haptic sleeve. At the end of the experiment, there will be space for the participant to comment on their experience.

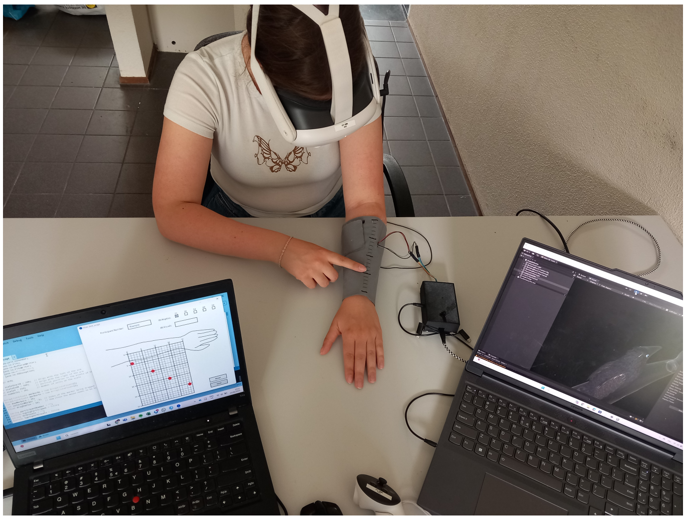

FIGURE 16: Set up of the user tests

5.5 Pilot tests

Three pilot tests were done to optimise user testing. From these pilot tests, it was found that there was still a slight delay between the haptics and visuals. There was no delay shown when testing with LEDs, but this might be because the LEDs are quicker to respond than the vibration motors. During the pilot tests, it was found that adding a 50ms delay to the visuals would result in seeing and feeling the bird hop at the same time. The idea of drawing a scale on the haptic sleeve arose from the first pilot test, as it was found that it was hard to recognise the location the participant was pointing to on the sleeve. Besides that, it was found that when the AR headset was not used during the tests with the haptic sleeve only, the headset might disconnect or show a loading screen. To prevent confusion for participants, the researcher needs to check if the headset is still properly connected before putting it on a participant. During the first pilot tests, the incongruency was tested both by slowing down and speeding up the visuals. It was noticed that speeding up the visuals felt unrealistic and made the illusion of the CRE disappear immediately. Therefore, it was decided to only test the incongruency by slowing down the visual feedback.

6 Results

The experiments were done with 25 participants, of whom one was left-handed and the others were all right-handed. The results of these experiments have been evaluated into heatmaps, where the columns 0 to 20 represent the scale going from the vibration motor at the elbow (0) to the motor at the wrist (20), and the rows resemble the different hops 1 to 4. The grey area indicates that only one participant has experienced haptic feedback there, while the dark blue indicates that ten or more participants have felt haptic feedback. Ten has been chosen as the maximum as there are not a lot of occurrences where there are more than ten participants feeling the same thing, except for the zero and one position, as these are felt pretty consistently by everyone. The average position, rounded off to an integer, is highlighted by a red dot. A legend of the heatmaps can be seen in Figure 17.

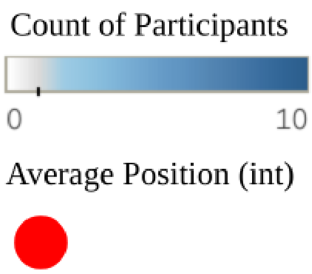

FIGURE 17: Legend Heatmaps of results

This chapter will first dive into the comparison between only haptics and the combination with visuals at different speeds, whereafter the incongruency will be discussed. Overall, it was found that the experience of the CRE differs a lot per participant, where some feel it is more distributed along the forearm while others only feel feedback at the locations of the vibration motors.

6.1 IBI 25ms

Looking at the results of the fastest sequence (see Figure 18), it can be seen that the sequence was often experienced to have only three hops. Considering only haptics, these hops were mostly felt at locations 0, 6 and 15. Three participants also noted that the last hop felt more like a sliding pattern. When implementing the visuals, it can be seen that the area where something has been experienced is more distributed, especially for the second and third hops. The second hop is, on average, felt closer to the middle. Even though there is only one position difference with only haptics, it can be seen that the blue area is more skewed towards the middle. The third hop stays the same, average-wise, but it can be seen that more people felt the hop somewhere in the middle when visuals are included. Participants did note that the visual sequence was quite fast to comprehend.

FIGURE 18: Results IBI 25ms

6.2 IBI 38ms

At 38ms it can be seen that some participants do not feel the fourth hop, especially when testing with only haptics. The most common patterns are the locations 1, 5, 15, 17. Adding visuals will result in a pattern of 0, 5, 14, 18. It can be seen that, including the visuals, the blue areas are more concentrated around the averages. This indicates that the visuals impact the haptic pattern in such a way that the hops are felt more equally distributed throughout the arm by most participants. Additionally, it can be seen that the fourth hop is felt more clearly when the visuals are added.

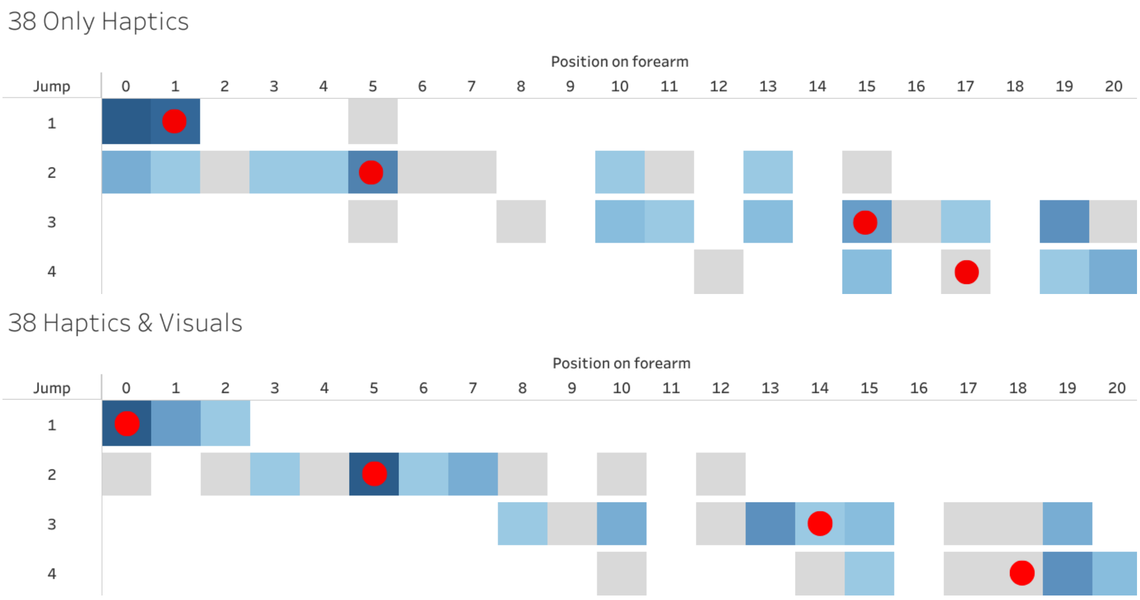

FIGURE 19: Results IBI 38ms

6.3 IBI 52ms

At 52ms the average pattern for only haptics is 0, 5, 13, 18. Compared to the faster speeds, the fourth hop is experienced more often at 52ms. One participant even noted that they felt a sliding sensation at the last hop. Integrating visuals results in a more dense pattern; 1, 6, 13, 16. The first, second and fourth hops are now more skewed towards the middle. One participant experienced five hops when the visuals were added.

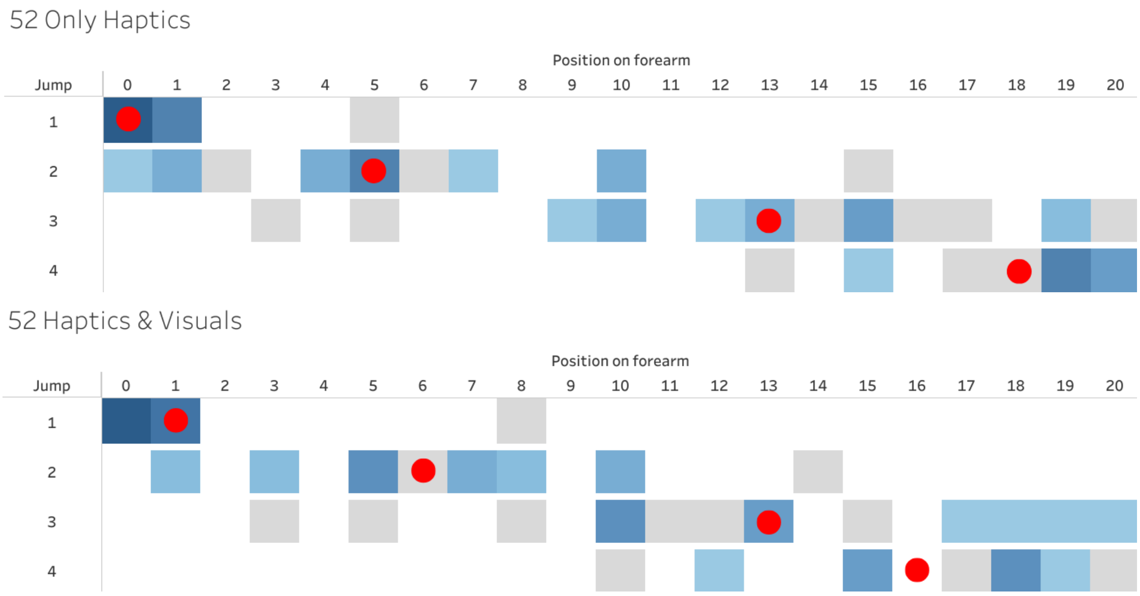

FIGURE 20: Results 52ms

6.4 IBI 60ms

At 60ms the pattern for only haptics is seen at 0, 4, 13, 18. Whereas including visuals shows 1, 5, 12, 16. The second and third hops do show more blue areas in the middle when visuals are implemented, suggesting the CRE is felt to be more equally distributed. Just like at an IBI of 52ms, the pattern, including the visuals, is more dense than the pattern without visuals.

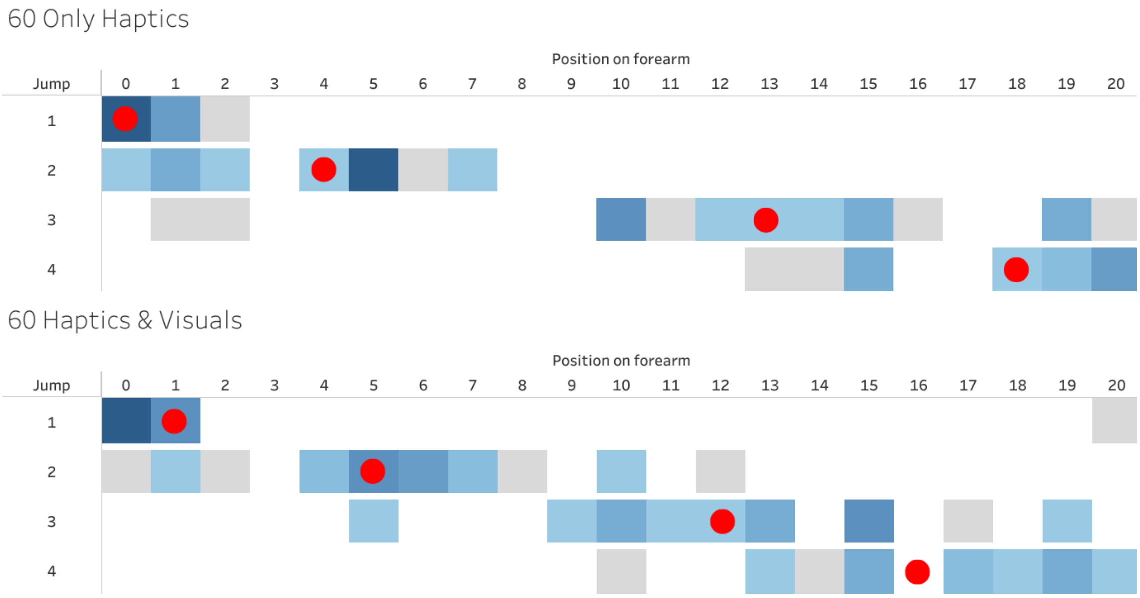

FIGURE 21: Results IBI 60ms

6.5 IBI 98ms

Due to unfortunate circumstances, a data loss occurred for the haptics and visuals at 98ms. Therefore, the results will be compared to the sequence of 98ms with a 25ms visual delay. When only looking at haptics, a pattern of 0, 4, 11, 17 can be found. It does stand out that the location of the second hop is quite distributed towards the elbow, whereas the third hop is distributed over the whole arm. One participant even experienced five hops. Adding a visual with 25ms delay, most participants experienced it similarly to having no delay. It can be seen that the second and third hops are less distributed and more towards the middle of the forearm. This does indicate that the CRE is felt more clearly. Adding the visuals also resulted in two participants feeling five hops.

As at an IBI of 98ms the visuals were easiest to comprehend, participants were asked to point out where they saw the crow hopping on their arm. These results can be seen in the 98 Only Visuals heatmap. This resulted in an average pattern of 1, 6, 11, 16. This pattern is more dense than the pattern which is often felt with only haptics. This can explain why the patterns get more dense once visuals are added.

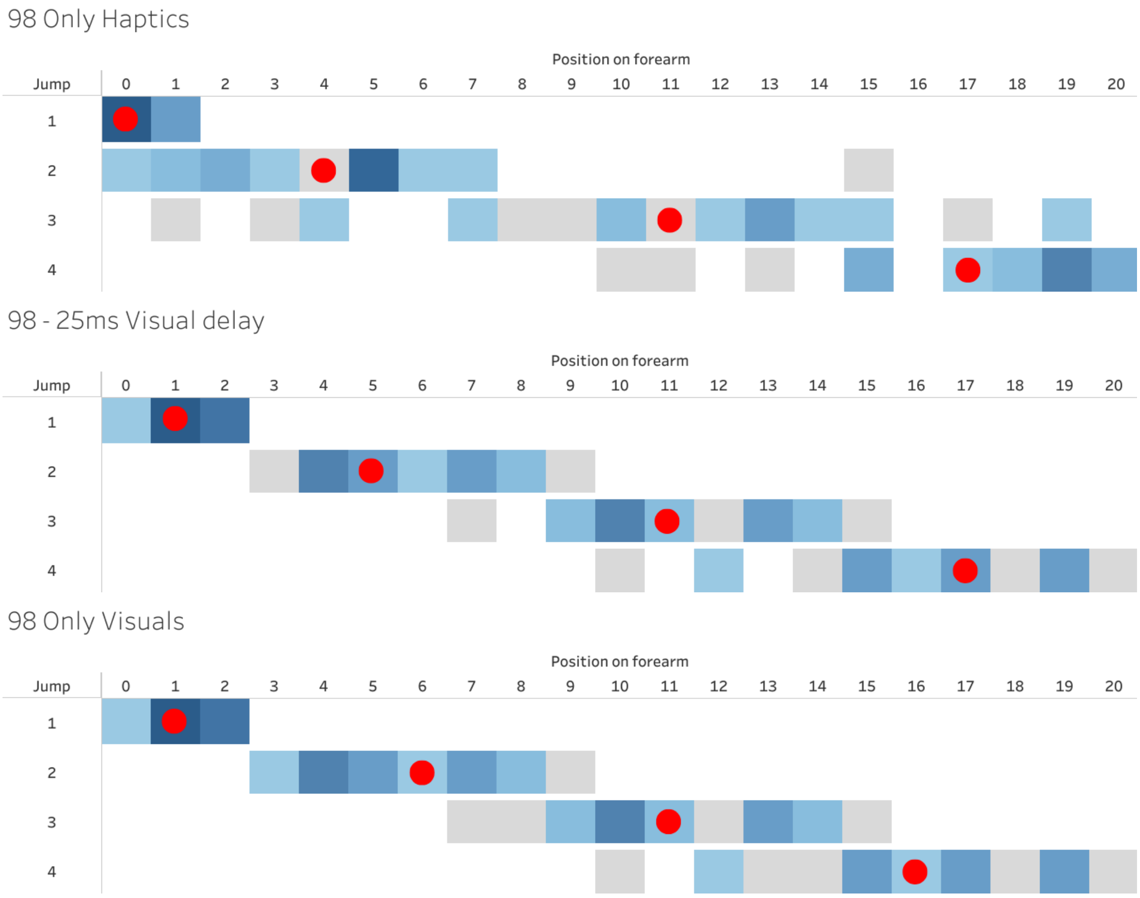

FIGURE 22: Results IBI 98ms (with 25ms Visual delay); haptics compared to visuals

6.6 Incongruency

It was found that at an IBI of 98ms the visuals seemed the most realistic, as with other speeds, the visuals tended to be too fast to fully comprehend. Therefore, this speed was used for testing how long a visual can be delayed before the illusion of the CRE disappears. To specify, this delay excludes the 50ms visual delay, which was added to synchronise the haptic and visual feedback. As mentioned before, and can be seen in Figure 22, participants experienced the hops distributed along the forearm. Some participants were very sensitive to the delay and noticed it immediately, whereas most participants did not notice the delay yet. At 50ms delay, more participants started to notice it, and at 75ms delay, most participants noticed a delay. A few participants were not aware of the delay at all.

Looking at the results, it can be found that the pattern tends to skew more towards the elbow when there is more delay. As there were some participants who did not notice any delay, the average pattern stayed quite similar. Nevertheless, it can be seen that for some participants, the illusion disappears, as the locations are only felt close to the vibration motor at the elbow. Especially from a delay of 100ms it can be seen that participants start to feel the second and third hop at the elbow.

FIGURE 23: Results IBI 98ms with visual delay 25-150ms

6.7 Additional comments

The participants were asked to point out where they experienced the visual feedback; these results can be seen in Figure 22. From these results, it can be seen that the participants experienced the locations where they saw the bird land quite differently. One participant even saw the first location above the elbow.

Overall participants liked the crow character and often started interacting with it by poking at it or trying to pet it. Most participants found the animation to be realistic, but some pointed out that it was still somewhat pixelated and easy to spot that it was not a real bird. This is also a result of the AR world being more pixelated than the real world, with which some participants are more immersed in the AR world instead of others. Besides that, participants commented that the realism could be improved by giving the crow a shadow and some more animations, like moving its head around.

Additionally, participants noted that it was quite hard to register, remember and point out the specific locations where they felt haptic feedback. Quite a lot of participants did feel that their experience changed when seeing the crow, as they were more focused on the visuals than the haptics.

7 Discussion

From the results, it can be seen that the participants can experience the CRE quite differently. Some will only feel haptic feedback at the motors, while others feel it equally distributed along the arm, and others feel it more skewed to one side of the arm. This is a cause of everyone having a different sensitivity to haptic feedback. Besides that, some participants might be more easily influenced by the visuals than others. The difference in participants can be seen in the results, as overall there is quite a big distribution between the locations of a hop; there is never one concrete point where all participants have felt something. Therefore, the average patterns should not be the leading results, as the heatmaps show more information. A hop might occur at the same position, but for one instance, the positions are distributed along the arm, while for another instance, the positions are surrounding the average. For future research, it would be interesting to sort the results into groups depending on the sensitivity towards haptic and visual feedback.

As mentioned by the participants, it was quite hard for them to register and remember where they had felt haptic feedback. Even after feeling the same sequence multiple times, not everyone was completely sure about their answers. Besides that, the researcher might be able to make mistakes by misremembering the locations, causing the input to be slightly off. It is quite important to have a large number of participants, so these errors become less relevant.

The current Processing script (see Figure 15), used to document the experiences of the participants, is somewhat restrictive. It can only input a maximum of four hops, as it was not anticipated that participants would feel more than that. This caused the researcher to be unable to input these results completely. Likewise, a sliding sensation could also not be indicated in the results themselves. Similarly, if participants experience the feeling or the sight of the crow outside of the elbow to wrist range, this could not be documented. For this research, these results were documented with a closely resembling pattern and a note on the questionnaire (see Appendix F).

As can be seen in Figure 22 in the only visuals heat map, the participants experience the visual feedback quite differently. This is because body tracking is not optimised yet. For this experiment, calculations were used to place the bird on the arm. As there are a lot of different sizes and forms of forearms, these placements are not the same for everyone. Seeing the bird in a different location can cause haptic feedback to be felt at that location, as participants often noted that they felt where they saw something. Most participants saw the bird hopping closely to the elbow, with locations 1, 4, 10, and 15 being the most common patterns. This can explain why, when the visuals get added, the haptic feedback gets skewed towards the elbow.

The haptic sleeve is fastened with a corset-like elastic (see Figure 10). The scale on the front of the sleeve should be placed on the middle of the forearm, to make it readable and to get the best positioning of the vibration motors. During the experiments, it was noticed that it was quite hard to position the sleeve correctly. The participant turned around their arm so the researcher could fasten the elastic, but when turning back the arm, the sleeve was often misplaced. Sometimes this causes the vibration motor on the wrist to sit on a bone, where haptic feedback is felt less prominently. Misplacement could be slightly corrected in case the sleeve was not fastened tightly. In order to feel the vibration motors, the sleeve should be fastened tightly. Positioning the sleeve without disconnecting the wires and fastening it tightly enough takes some practice. Some of the results might be slightly affected by the positioning of the sleeve not being optimal.

Comparing the results of only haptics over different speeds is quite difficult. Ziat et al

[21] found that the CRE benefitted from a faster speed (24ms), but from these results, it seems that faster speeds become hard to comprehend or become more of a sliding sensation. The difference in these results might be due to using different haptic feedback patterns and different kinds of vibration motors. Comparing the average patterns of all the speeds, the sequence with an IBI of 52ms seems to be the one where the four hops are almost equally distributed along the length of the forearm.

In conclusion, the results can be affected by the difference in haptic and visual experience of people, human errors, limitations in documenting options or displacement of the sleeve. These factors should be taken into account when looking at the results; nevertheless, the results are still trustworthy due to the large sample size.

8 Conclusion

From background research, it follows that modalities are connected either by passing on information or by combining information from multiple modalities. The experience of these modalities can be affected by featural, temporal and spatial aspects. These aspects can cause one of the modalities to become dominant and influence the experience of another modality, creating an illusion. The CRE is an illusion where someone experiences hops going down the arm, even though haptic feedback is only given at two points. When an AR visual is added, the haptic experience of the CRE is influenced. Like with many cross-modal illusions, the visuals become dominant, seeming that the haptic feedback is felt at the same location as the visuals. This does mean that the realism of the visuals becomes important, as the illusion gets disrupted by confusion due to surrealism. It should be taken into account that people experience input on modalities quite differently. Therefore, not everyone's experience is influenced by AR to the same extent. Contrary to previous research, this research suggests that a sequence with an IBI of 52ms creates the illusion of the CRE the best. Faster speeds can be too fast to comprehend, resulting in fewer hops or a sliding pattern. Slower speeds can diminish the illusion but seem to be more impacted when adding a visual. It was found that the sequences were affected by the visual at all speeds, as the haptic illusion became more robust. The sequence with an IBI of 98ms experiences the largest impact and seems to be the most realistic, as faster visuals are harder for the brain to comprehend and therefore harder to link to the haptics. Synchronisation of the visual and haptic feedback is crucial for realism, as incongruency causes confusion and diminishes the illusion. In case the visuals appear faster than the haptics, the illusion disappears immediately. The visuals can be slowed down by a maximum IBI of 100ms delay before the illusion is diminished. Therefore, it is better that the visual is too slow instead of too fast.

For future research, it is recommended that the positioning of the animal be optimised by improving the body tracking of the arm. Besides that, it is advised to improve the fastening mechanism of the sleeve, as well as to improve the data collection program. This topic can also benefit from the exploration into the effect of a sliding pattern and some slower haptic sequences to discover how slow the CRE and visuals can be before the illusion is diminished.

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Appendices

A Circuit Schematic Haptic Sleeve

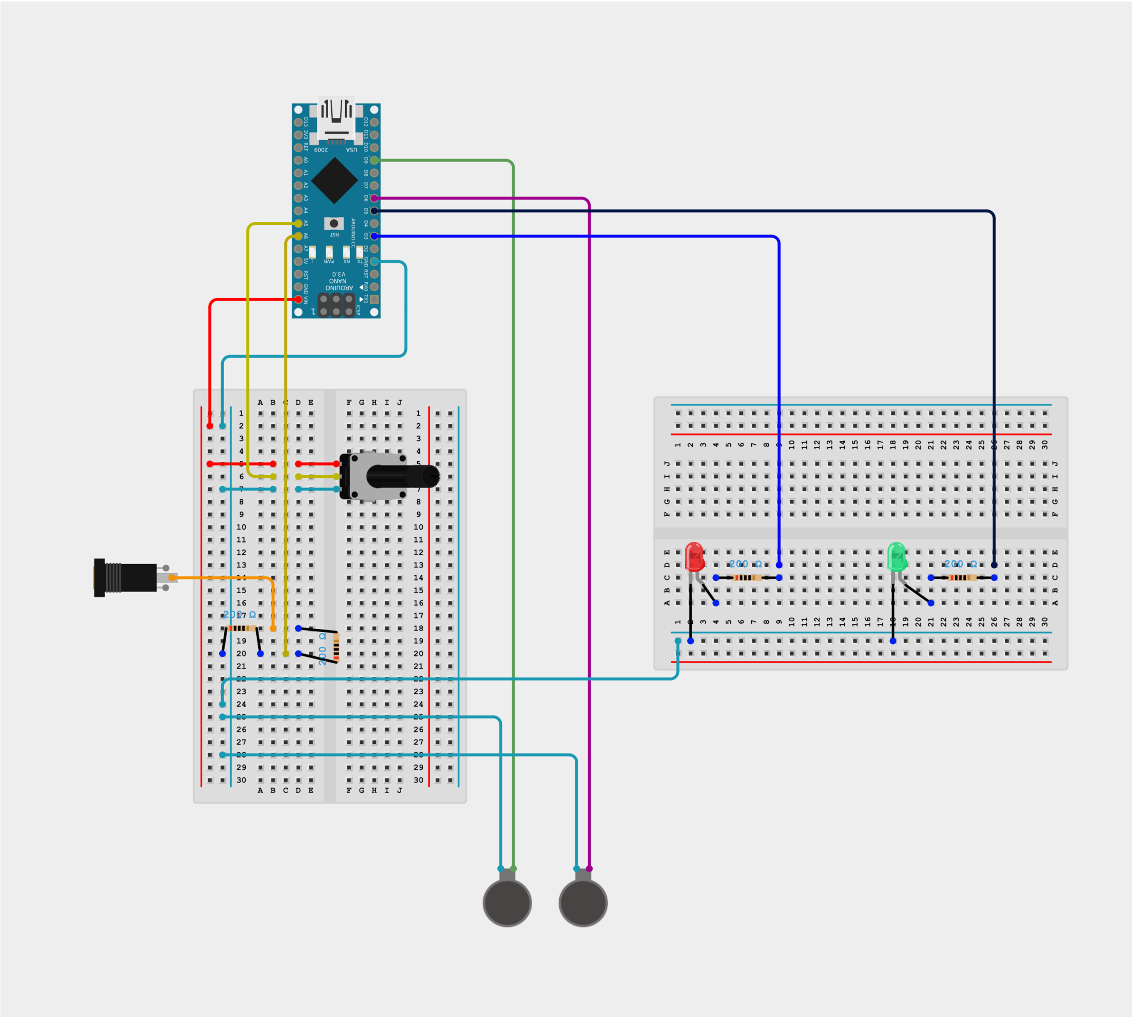

FIGURE 24: Circuit schematic

B Consent Form Expert Interview

Consent Form for Influence of Cross-Modality on the Cutaneous Rabbit Effect

YOU WILL BE GIVEN A COPY OF THIS INFORMED CONSENT FORM

Please tick the appropriate boxes	**Yes**	**No**
Taking part in the study		
I have read and understood the study information dated [12/03/2025], or it has been read to me. I have been able to ask questions about the study and my questions have been answered to my satisfaction.	○	○
I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions and I can withdraw from the study at any time, without having to give a reason.	○	○
I understand that taking part in the study involves that the answers I give during this interview will be written down and audio recorded.	○	○
Use of the information in the study		
I understand that information I provide will be used for a Creative Technology bachelor's Thesis. The data that will be collected are the answers to the interview questions. The participant can choose to withdraw their data, till the end of the experiment after this the data will be anonymized.	○	○
Either 1 or 2 should apply to you:		
1. I understand that personal information collected about me that can identify me, such as [e.g. my name, will not be shared beyond the study team.	○	○
2. I agree that my real name can be used for quotes	○	○
I agree that my information can be quoted in research outputs	○	○
Consent to be Audio Recorded		
I agree to be audio recorded.	○	○
Future use and reuse of the information by others		
I give permission for the interview answers that I provide to be archived in the thesis repository of University of Twente, so it can be used for future research and learning.	○	○
I give the researchers permission to keep my contact information and to contact me for future research projects.	○	○

UNIVERSITY OF TWENTE.

Signatures

______________________ ______________________ ________

Name of participant Signature Date

I have accurately read out the information sheet to the potential participant and, to the best of my ability, ensured that the participant understands to what they are freely consenting.

_________________________ ___________________ ________

Researcher name [printed] Signature Date

Study contact details for further information:

Ilse de Haan

i.t.dehaan@student.utwente.nl

Supervisor:

Angelika Mader

a.h.mader@utwente.nl

Contact Information for Questions about Your Rights as a Research Participant

If you have questions about your rights as a research participant, or wish to obtain information, ask questions, or discuss any concerns about this study with someone other than the researcher(s), please contact the Secretary of the Ethics Committee Information & Computer Science: ethicscommittee-CIS@utwente.nl

C Information Sheet Expert Interview

Information Sheet Expert Interview “Influence of Cross-Modality on the Cutaneous Rabbit Effect”

Purpose of the Study
The objective of this research is to discover what influence an Augmented Reality visual has when it is added simultaneously to the haptic input of the Cutaneous Rabbit Effect (CRE).

Background and Significance
Cross-modal experiences happen when two or more cross-modal inputs are being used, which sometimes can cause an illusion. For example, the double flash illusion, where one flash is experienced as two flashes when hearing two rapid beeps. This means that the visual experience is influenced by the auditory experience. This research aims to discover what influence visual input has when it is added simultaneously to the haptic input of the CRE. This is a sequence of rapid taps at the wrist followed by rapid taps at the elbow, which results in feeling taps going from the wrist up to the elbow, even though no haptic stimulation was given in the middle of the forearm.

Experiment
It is possible to withdraw from this study at any time. You can do this by notifying the researcher. You will be asked questions on your knowledge of the CRE and the effects of Augmented Reality or Virtual Reality on the CRE. You can choose not to give an answer to a question. The interview will be recorded by an audio recorder, and the audio recording will be deleted as soon as all the relevant information from the interview is written down.

Data privacy
Personal information will be safeguarded, by maintaining confidentiality and de-identifying data. No retraceable personal details will be published in the research, instead, the data will be categorized by participant numbers. The de-identified data will be used in a Creative Technology bachelor’s thesis.

Contact details for future questions
Ilse de Haan i.t.dehaan@student.utwente.nl
Supervisor: Angelika Mader a.h.mader@utwente.nl

Contact Information for Questions about Your Rights as a Research Participant
If you have questions about your rights as a research participant, or wish to obtain information, ask questions, or discuss any concerns about this study with someone other than the researcher(s), please contact the Secretary of the Ethics Committee Information & Computer Science: ethicscommittee-CIS@utwente.nl

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D Consent Form User Study

Consent Form for Influence of Cross-Modality on the Cutaneous Rabbit Effect User Study

YOU WILL BE GIVEN A COPY OF THIS INFORMED CONSENT FORM

Please tick the appropriate boxes	**Yes**	**No**
Taking part in the study		
I have read and understood the study information dated [09/05/2025], or it has been read to me. I have been able to ask questions about the study and my questions have been answered to my satisfaction.	○	○
I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions and I can withdraw from the study at any time, without having to give a reason.	○	○
I understand that taking part in the study involves indicating where I felt haptic feedback and answering questions on the experiment, which will be documented in writing by the researcher.	○	○
Risks associated with participating in the study		
I understand that taking part in the study involves the risk of experiencing dizziness and/or headaches due to wearing the AR headset for a long time.	○	○
Use of the information in the study		
I understand that information I provide will be used for a Creative Technology bachelor's thesis. The data that will be collected are the test results, age, left- or right-handed. *The data will be anonymized by using a participant number on the questionnaire without keeping a key that links the number to the participant.* The participant can choose to withdraw their data until the end of the experiment, after this the data will be anonymized.	○	○
I understand that personal information collected about me that can identify me, such as my name will not be shared beyond the study team.	○	○
I agree that my information can be quoted in research outputs	○	○
Future use and reuse of the information by others		
I give permission for the anonymizes questionnaire data that I provide to be archived in the thesis repository of the University of Twente, so it can be used for future research and learning.	○	○

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Signatures

______________________ ______________________ ________

Name of participant Signature Date

I have accurately read out the information sheet to the potential participant and, to the best of my ability, ensured that the participant understands to what they are freely consenting.

Ilse de Haan ___________________ ________

Researcher name Signature Date

Study contact details for further information:

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E Information Sheet User Study

Information Sheet Expert Interview "Influence of Cross-Modality on the Cutaneous Rabbit Effect"

Purpose of the Study

The objective of this research is to discover what influence an Augmented Reality visual has when it is added simultaneously to the haptic input of the Cutaneous Rabbit Effect (CRE).

Background and Significance

In daily live humans use a combination of their senses to perceive experiences. Humans use this cross modality effortlessly, without really knowing how they do it. In case the perception of an experience is wrong, this is called a cross-modal illusion. This research focusses on a haptic illusion, the Cutaneous Rabbit Effect (CRE), where multiple taps at the elbow followed by taps at the wrist can result in a feeling of taps going down the arm, even though no haptic feedback was given in the middle of the forearm. To make a haptic illusion more immersive, an Augmented Reality (AR) visual can be used to turn it into a cross-modal illusion. By implementing an AR visual on the CRE the influence of visual input on the haptic input will be evaluated.

Experiment

It is possible to withdraw from this study at any time. You can do this by notifying the researcher. The experiment will make use of a sleeve which gives haptic feedback and an Augmented Reality (AR) headset. This headset can cause discomfort, especially when used for a long time. In case the headset causes dizziness or headaches you should request the researcher to stop or pause the experiment. The experiment starts with only haptic feedback given by the sleeve. You will be questioned on how you experience this haptic feedback. Next step is to add the AR visual and you will be asked how the visual affects the haptic experience. After the experiment the researcher will interview you on the pleasantness of the experience and you are able to give any other input you would like. You can choose not to give an answer to a question. Your answers will be written down by the researcher.

Data privacy

Personal information will be safeguarded, by maintaining confidentiality and de-identifying data. No retraceable personal details will be published in the research, instead, the data will be categorized by participant numbers. The de-identified data will be used in a Creative Technology bachelor's thesis.

Contact details for future questions

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F Additional Questionnaire User Study

#_____

User test: Influence of Cross-Modality on the CRE

Test done by: Ilse de Haan

Which is your dominant hand?

- Left
- Right

Only haptic feedback

25, 38, 52, 60, 98

Haptics and visuals

25, 38, 52, 60, 98

#_____

Incongruency

Test with an IBI of 98

Which feels most congruent?

+75	
+100	
+150	

Further comments

G Use of Generative AI tools

During the preparation of this work the author used ChatGPT in order to understand the code of the original project as well as to help resolve issues in the Unity and Processing code. After using this tool/service, the author reviewed and edited the content as needed and takes full responsibility for the content of the work.