Let Me Grab This: A Comparison of EMS and Vibration for Haptic Feedback in Free-Hand Interaction

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ABSTRACT

Free-hand interaction with large displays is getting more common, for example in public settings and exertion games. Adding haptic feedback offers the potential for more realistic and immersive experiences. While vibrotactile feedback is well known, electrical muscle stimulation (EMS) has not yet been explored in free-hand interaction with large displays. EMS offers a wide range of different strengths and qualities of haptic feedback. In this paper we first systematically investigate the design space for haptic feedback. Second, we experimentally explore differences between strengths of EMS and vibrotactile feedback. Third, based on the results, we evaluate EMS and vibrotactile feedback with regard to different virtual objects (soft, hard) and interaction with different gestures (touch, grasp, punch) in front of a large display. The results provide a basis for the design of haptic feedback that is appropriate for the given type of interaction and the material.

Author Keywords

Large displays, tactile feedback, haptic feedback, electrical muscle stimulation, free-hand interaction.

ACM Classification Keywords

H.5.2. User Interfaces: Input devices and strategies, Haptic I/O.

INTRODUCTION

With the advent of the Nintendo Wii controllerand the Microsoft Kinect, mid-air interaction in front of (large) displays is becoming increasingly popular. Much effort has been put into making body and gesture recognition robust and accurate [28] and, consequently, novel applications emerged both in research and in the commercial sector. To make such interactions convincing and immersive, multiple modalities are required. However, in particular haptic feedback for mid-air interaction, is still in its infancy and existing solutions restrict the user in several ways. Controllers like the Wii, do provide vibration feedback, but require the user to hold the controller in their hands. Moreover, this approach has limitations in rendering more advanced haptic feedback, such as for creating the illusion of holding a physical object.

Figure 1: Free-hand interaction with haptic feedback: A user receives haptic feedback when approaching an object shown on the screen.

Further approaches to make simulated physical objects palpable include gloves [20] or exoskeletons [4]. However, those devices are in general cumbersome to wear and operate, particularly in public environments.

In this work we focus on haptic feedback for free-hand interaction without encumbering the user's hand. We aim to make free-hand interaction more realistic and convincing by providing haptic feedback in a way that is easily applicable in daily life. When a surgeon needs the flexibility and the tactile sense of the hands for handle surgical instruments the hand cannot be covered. Therefore the wrist and the lower arm are a particularly well suited body positions for applying haptic feedback in free-hand interaction. Wristband devices are already popular for life logging applications (e.g., Nike+ Fuelband[1], Jawbone Up[2]).

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[1] Nike+ Fuelband: `www.nike.com/FuelBand_SE`

[2] Jawbone Up: `www.jawbone.com/up/international`

The design of haptic feedback with high variability and similarity to physical touch events is still an unsolved problem. Today, vibration is the most popular technology for haptic feedback and integrated into many mobile devices. At the same time, electrical muscle stimulation (EMS) is becoming a hot topic as it offers a particularly wide range of different strengths and qualities with reasonable power consumption and device size and it does not require any mechanics. A number of devices incorporating EMS are already commercially available, including systems for massages (e.g., ProRelax[3]), or for fitness (e.g., Miha Bodytec[4]). In research, such system have already been used to provide haptic feedback for interaction [15, 25]. However, there is still a considerable knowledge gap about the perceived qualities of EMS feedback compared to feedback based on vibration

In this work, we provide a comparison of EMS and vibration as feedback methods for free-hand interaction. We first explore the design space of haptic feedback for free-hand interaction. Creating this design space allows us to identify important properties of haptic feedback methods. Using this design space as a basis we then present two studies that compare EMS to vibration feedback. The first experiment investigates (a) the differences in feedback strength for both EMS and vibration, and (b) identifies which levels of feedback strength between vibration and EMS correspond to each other. We then use the results for a follow-up experiment, where we investigated how to select the feedback intensity for EMS and vibration in a way that well reflects (a) different types of interactions (touch, grasp, punch) and (b) different materials (soft, hard) in free-hand interactions with large displays. In these experiments, different objects were shown on a large screen and we asked the user to perform a certain free-hand interaction (e.g., virtually touching a stone in mid-air – see Figure 1). The results show that users rate the appropriateness significant higher for the EMS feedback on hard material.

The contribution of this work is threefold. First, we sketch the design space for haptic feedback in free-hand interaction settings. Second, we report on the design and development of a haptic feedback system based on EMS and vibration. Third, we present results from two studies that investigates how to design haptic feedback to best reflect different types of interaction with different materials.

BACKGROUND AND RELATED WORK

Several research projects looked at providing haptic feedback for interacting with remote systems and in virtual environments [9, 11, 30]. Free-hand, mid-air, and full-body gestures are getting more popular since infrared and depth camera-based tracking systems such as the Kinect, LEAP Motion[5], PrimeSense[6], and Xtion[7] become affordable and easy to use.

In the following, we revisit related work from different areas. First, we look into how haptic feedback can stimulate different senses. Then we look at technologies to create haptic feedback before focusing on prior work that investigates haptic feedback in free-hand interaction. Finally, we look at electric feedback and how it has been applied in HCI.

Effects of Haptic Feedback

Haptics provide a rich source for creating feedback in different ways. The feedback can stimulate a number of different nerves and receptors in the human skin, including free and sensory hair nerves as well as receptors for cold, heat, touch, pressure, and pain [12]. Prior work has looked at providing haptic feedback through water, air, pressure, motors, vibration, temperature, and electric currents [11, 27, 29]. Stimulating particular nerves and receptors makes the user (partly) perceive certain properties of a (virtual) object, such as resistance or gravity, which makes it particularly useful for our work. Furthermore, prior work shows that haptic feedback can result in an increase of recognition, precision, efficiency, perception, and user experience [12, 14, 17, 19, 23, 24, 33].

Technologies for Haptic Feedback

Haptic stimuli are used in research and commercial products for feedback. Haptic feedback is used to simulate the properties of virtual or remote objects (e.g., CyberGrasp[8], Phantom Omni[9]). In this way, haptic feedback can make interaction with the remote system more realistic for the user [30]. In most cases, such systems are used in desktop or in specialized environments. Application areas include medicine (e.g., feedback while cutting tissue) or controlling robots [36].

To use haptic feedback technologies, the user is often restricted to a fixed position and rather bulky apparatus are required. For example, Nitzsche et al. [21] present a mobile haptic system moving in front of the user during interaction. For motion-intensive interaction techniques (e.g., gestures), small, portable devices can be used, that require the user to wear gloves or markers. Ooka and Fujita present a device, that aims to make grabbing and manipulating virtual objects more realistic [24]. Nikolakis et al. [20] compare haptic feedback devices for manipulating objects in a virtual reality environment. However, haptic feedback systems usually obstruct hand and forearm and restricts both the tactile sense and the mobility of the hand. Hence, such systems are usually cumbersome to wear for a long period of time.

Haptic Feedback in Free-Hand Interaction

Following the notion of Nancel et al. [18], we use the term *free-hand interaction* to describe interactions based on mid-air gestures [1, 2] that do neither need a physical connection to the display nor a handheld controller. Free-hand interactions are characterized by not limiting the degree of freedom for hand movements or the perception of tactile stimuli.

Different forms of free-hand interaction have been investigated, focusing on the restriction of sensory capabilities and social acceptance. Obrist et al. [22] present ultrasound

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[3] ProRelax: `www.prorelax.com`

[4] Miiha Bodytec: `www.miha-bodytec.com`

[5] LeapMotion: `www.leapmotion.com`

[6] PrimeSense: `www.primesense.com`

[7] Xtion: `www.asus.com/Multimedia/Xtion`

[8] CyberGrasp: `www.cyberglovesystems.com/products/cybergrasp/overview`

[9] Phantom Omni: `geomagic.com/en/products/phantom-omni/overview`

feedback with 64 ultrasound transducers in an 8x8 array. The transducers provide different feedback frequencies and rhythms. In AIREAL [29], focused air pulses are precisely shot towards the user's point of interaction. However, the approach is limited to a distance of 1 m. Similarly, AirWave [10] provides air feedback with a maximum distance of 3 m. The air-vortex and ultrasound feedback technologies are rather limited in terms of distance (AirWave up to 3 m, ultrasound less than 10 cm), feedback force, and spectrum of feedback. Moreover, they are not suitable for multi-user interaction and the environment needs to be augmented to provide feedback.

Large and inflexible apparatuses impede the user with regard to mobility and during interactions based on body posture or free-hand gestures. Small and mobile systems usually obscure the hands and restrict the tactile capabilities. User-independent systems require the surrounding space to be instrumented. As a result, such systems are usually limited with regard to feedback strength, interaction distance, and number of users. To tackle these issues we investigate the use of electrical muscle stimulation (EMS) for free-hand interaction.

Electrical Feedback

Electrical muscle stimulation has been investigated since the 18th century. In its current form, EMS goes back to the 1970s, where, for example, Strojnik used it for therapies [32]. Strojnik investigated how complex muscle movements can be supported through muscle stimulation and Gillert [8] describes different application areas. Porcari et al. investigated, how EMS impacts on different human body parts [26].

Portable EMS devices were developed by Brewing [3] and Miha Bodytec[10], mainly for fitness training. For injecting the electric current, users need to wear vests and wristbands including electrodes. Whereas electrodes can be implanted, surface electrodes (i.e., adhesive electrodes, plate electrodes) are used in home environments or for fitness training, due to their ease of use and acceptability.

In the field of Human-Computer Interaction (HCI), using EMS to provide feedback has received considerable attention. For instance, PossessedHand [34, 35] is a device for controlling finger-joints by EMS. The authors show that electrical feedback is suitable for mixed reality, navigation, and learning to play instruments. In [13] EMS was tested as a feedback method for a 3D computer game. Farbiz et al. [5] investigate mixed reality EMS feedback for visualizing a ball that can be hit by a real racket. Lopes and Baudisch [15, 16] used EMS in a mobile game as force feedback. They investigate the length of electrical feedback signals and test the amount of force a user can provide. Pfeiffer et al. [25] used EMS for interacting with large displays in public space. They provide EMS feedback in a Kinect-based interactive game.

Vibration Feedback

Vibration feedback is well understood in research as well as in commercial products. An overview of the history of haptic feedback is presented by Stone [31]. Okamura et al. [23] investigated different vibration models for material behaviors such as wood and steel for virtual environments. Vibration has been used in many products. For instance, it has been added to the touch panel of a mobile device [7].

DESIGN SPACE FOR HAPTIC FEEDBACK

For designing haptic feedback in free-hand interaction and to be able to provide a comparison taking important dimensions into account, we sketch a design space for creating haptic feedback for free-hand interaction. We focus on research prototypes as well as consumer devices. This design space is later on used to explore specific dimensions without confounding different aspects. Based on a literature review, we identified the following dimensions of the design space.

Feedback Technologies

There are many different technologies available that induce haptic feedback. One of the most common feedback technologies is vibration feedback that is used in almost every mobile phone, tablet, or game controller. Other feedback technologies include EMS feedback or air currents. Such technologies have different abilities to provide feedback ranging from tactile prickles on the surface of the skin or physical haptic movements of limbs.

Sensing capabilities

The haptic sensing capabilities are based on the different nerves in skin, tissue, and muscles all of which are stimulated by touch, pressure, and heat. Furthermore, the number of nerves varies at different position on the human body. Therefore, some positions are more sensitive to haptic feedback than others. For instance, the finger tips are very sensitive compared to the back. This lack of sensitivity can be adapted by the size of the stimulated area. Furthermore, the sensitivity changes over time because of the habituation during the stimulation.

Position on the Body

In cases where haptic feedback is applied through a device on the user's body, a number of different positions are possible. These include the fingers, the forearm, the upper arm, the torso, the head, the legs, and the feet. Applying feedback to each of these positions works differently well and the choice for a position usually depends on the action for which feedback should be applied (playing football vs. grabbing something with the hands).

Stimuli Characteristics

When applying the feedback, the following characteristics have an influence on haptic perception: the strength of the applied stimuli, the duration, and the stimuli form over time. The form of the haptic stimuli can follow the characteristics of a continuous, an alternating (on/off), or an increase or decrease sequence. Combinations of these stimulus create different rhythm over time.

Feedback Type

Haptic feedback can be used for different purposes. We define feedback that is used to make the user aware of a certain status (e.g., that he executed an action) as *supportive*. Compared to

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[10] Miha Bodytec: `www.miha-bodytec.com`

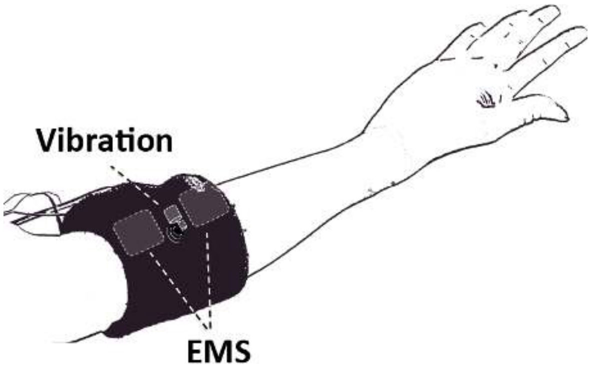

Figure 2: Vibration and EMS feedback placed on the forearm.

this rather implicit form, we define *informative* feedback to transmit information (i.e., similar to Morse code). In addition, this can be used to transfer information in a privacy protective way. Finally, it can be used for warnings, for example, the feedback is provided as soon as users leaves the area in which they can be optimally recognized by a sensor (e.g., Kinect).

Content Characteristics

The content characteristics that are being simulated through the feedback are important as well. This is in many cases a continuum, such as simulating soft or hard surface, a smooth or rough surface, or a slow or fast movement.

Input Gesture

The feedback that is provided to the user depends on the gesture that is performed to achieve a realistic feedback. There are several gesture that can be done in mid-air (e.g., virtually touch or grab).

PROTOTYPE

We developed an EMS feedback and a vibration feedback prototype to explore the *feedback technologies* dimension of the design space. Both prototypes are applying their feedback on both forearms (*position on the body*) to keep the hands and wrists free (cf., Figure 2). This is particularly useful if the prototypes needs to be embedded into clothing later on. The communication of both prototypes is realized with an Arduino Uno[11] that controls each of them independently. For both prototypes, the *impulse characteristic* is a simple on/off pattern of $750\,ms$, following the findings of Lopes and Baudisch [15]. The communication between the prototypes and the control software is realized using a WiFi-module. Both prototypes and the Arduino Uno controller weight together about $580\,g$ including battery. Furthermore, we would like to emphasize that with these prototypes we focus on free-hand interaction as a special form of mid-air interaction [18]. In contrast to free-hand interaction, the latter one may also include forms of interaction that require users to hold a device.

EMS Feedback

	Vibration		EMS	
Level	Speed (rpm)	SD	Current (mA)	SD
1	1390	0.51	4.10	0.25
2	2960	0.67	7.24	0.30
3	3876	0.53	10.12	0.23
4	4590	0.65	12.74	0.21
5	5267	0.73	14.50	0.18
6	5835	0.59	18.50	0.28
7	6274	0.65	19.06	0.28
8	6748	0.61	19.64	0.28
9	7274	0.49	21.82	0.17
10	7959	0.63	23.22	0.21

Table 1: Speeds of the vibration motor and corresponding currents for EMS.

The EMS prototype is build upon an off-the-shelf EMS massage device (Prorelax TENS+EMS DUO[12]). The system uses a pulse width of $260\,\mu s$ and a constant pulse frequency of $60\,Hz$ using a stable modulation scheme with a sawtooth waveform. In total, the device has 24 different strength levels. In a pretest, we explored the different levels and identified 10 different levels (1-10) that could be suitable for providing haptic feedback on the forearm. Regarding the impulse-time intensity curve [6] the current should be between $10\,mA$ and $40\,mA$, so that users can feel the feedback but do not suffer any pain. Therefore, we discarded level 1 and 2 (current lower than $10\,mA$) as well as level 10 (lower than $40\,mA$ but uncomfortable for users). The standard deviation (SD) is within 6% of the current. An overview can be found in Table 1. The device controls the different levels of current depending on the user's skin resistance. For applying the feedback to the user, two $40x40\,mm$ self-adhesive electrode pads were used (Figure 2). These pads were placed with a distance of $2\,cm$ on the forearm over the flexor carpi radialis. The EMS impulse leads to a contraction of muscles of the forearm, which forces hand and middle finger to move upwards.

Vibration Feedback

The vibration feedback prototype uses a motor with a maximum speed of $8.000\,rpm$ (at $7.5\,V$) and an asymmetric weight of $2\,g$. Following the EMS prototype, the vibration motor strength was divided into 10 levels. The levels range from $1390\,rpm$ to $7959\,rpm$ (cf., Table 1). The standard deviation (SD) is smaller than 0.04% of the speed. The motor was placed within a wristband to fixate it on the forearm during usage. To make users perceive both types of feedbacks in the same place, the vibration motor is located between the EMS electrodes.

STUDY 1: INVESTIGATING INTENSITY

In the first step, we conducted a study investigating the intensity of EMS and vibration. We used two tasks to (1) gain comparable levels of EMS and vibration feedback and to (2) evaluate how easy EMS signals of different levels can be distinguished.

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[11] Arduino Uno: `http://arduino.cc/`

[12] Prorelax: `www.prorelax.com`

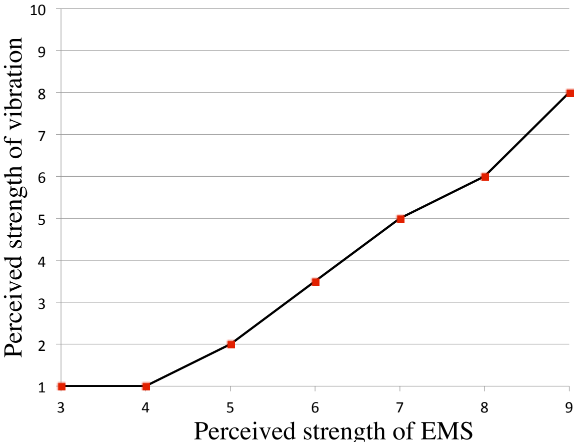

Figure 3: Results of task 1: Corresponding intensity levels of EMS and vibration feedback.

Participants and Procedure

In total, we invited 12 participants (8 male and 4 female) to take part in this study. They were aged 20 to 33 years ($M = 25.01$, $SD = 3.89$) and, except for one, right-handed. First, we provided participants a brief introduction to the study. We attached the devices at the dominant arm (cf., Figure 2). To make participants familiar with the feedback to expect during the study, we applied sample EMS and vibration feedback, including the entire range of intensity levels. We chose the EMS levels from very low to still acceptably strong feedback.

In the study, participants had to adjust the intensity of the vibration feedback to match the intensity of the given EMS feedback. Participants were able to replay EMS and vibration feedback with the chosen intensity. Then, the participants started with the tasks to (1) map the vibration level to EMS level and afterward to (2) distinguish different EMS levels. Afterwards, they filled in a questionnaire with 5 items rating scales ranging from 1 (totally positive) to 5 (totally negative).

Task 1: Generating Corresponding Intensity Levels

To evaluate EMS and vibration feedback in an application scenario, it is necessary to get corresponding feedback strengths. Therefore, we applied specific EMS levels to the user (level 3 to 9) in a counterbalanced order. The user‘s task was adjusting the vibration level to the given EMS level until the user perceived the feedback similar for both technologies. There was no time limit and participants were able to repeatedly perceive EMS and vibration feedback. Each EMS signal was presented five times in a randomized order to each participant.

Figure 3 depicts the results of the task. For EMS levels 3 and 4, the lowest vibration level was already perceived to be more intensive. For the remaining levels, there is a close to linear correlation. Hence, we decided to use EMS levels 5 and 8 and the corresponding vibration levels 2 and 6 for study 2.

Task 2: Distinguishing Vibration and EMS Signal

In many cases, different strengths of haptic feedback are required (e.g., for different actions or content items). Hence, it is necessary to create feedback users can distinguish. In this task, participants should differentiate which level is more intense. Two different EMS signals were provided after each other. We used EMS level 6 as a baseline and a second signal with a level between 3 and 9. Thus, we have a difference of 0 to 3 levels.The order in which the signals are presented to the user is counterbalanced as is the position in which the baseline is presented (as first or second stimulus).

The success rate is 60% for one level of difference, 90% for two levels, and 100% for three levels. Thus, we used three levels of difference in feedback strength for the second study.

Questionnaire

The results of the questionnaire show that, based on a 5-Point Likert scale (1=very easy, 5=very difficult) participants felt that they can distinguish the different feedback-levels easily (EMS: $Mdn = 2$, $MAD = 1$, Vibration: $Mdn = 2.5$, $MAD = 0.5$). Furthermore, both kinds of feedback are perceived immediately (EMS: $Mdn = 1$, $MAD = 0$, Vibration: $Mdn = 1.5$, $MAD = 0.5$). Questions about the comfort ($Mdn = 3$, $MAD = 1$) and whether participants felt that EMS could easily be applied in a real-world setting ($Mdn = 2.5$, $MAD = 1$), received average results. Asked for their preferences, participants did not have a clear preference for one of the methods ($Mdn = 3.5$, $MAD = 1.5$, 1=EMS, 5=vibration).

Limitations

We acknowledge the following limitation of the study. The system automatically adjusts the current depending on different skin resistances. However, the system is limited to a specific spectrum that it can compensate. For instance, it can not compensate the current for all possible variations. So it is possible that a user with very dry skin (i.e., skin resistance of more than 700Ω) subjectively perceives level 5 (with a current of $13\,mA$) to be lower than a user with very wet skin (i.e., skin resistance of less than 400Ω) perceives level 4 (with current of $14\,mA$).

STUDY 2: EXPLORING HAPTIC FEEDBACK

The aim of the second study was to find out, how feedback should be designed to best reflect (a) the gesture a user is performing (such as grabbing an object) and (b) the properties of the object the user is interacting with (e.g., whether it is soft or hard). In this way we aim to lay the foundation for more realistic and distinguishable haptic feedback. As feedback types we tested EMS and vibration, each with a low and a high intensity level (EMS$_{low}$, EMS$_{high}$, vibration$_{low}$, vibration$_{high}$)

As has been discussed in the design space, a number of gesture exist that could be used for free-hand interaction with content on the screen. In this study we focus on three common gestures: grabbing, touching, and punching an object. With regard to the object characteristics, we focus on the distinction between soft and hard objects to have two opposite types of material behavior.

Participants and Procedure

In total, we invited 20 participants for the study (13 male and 7 female). They were aged from 21 to 62 ($M = 27.55$, $SD = 8.61$). All participants were right handed.

We tested in our study two feedback methods (vibration and EMS) and two materials characteristics (hard and soft) with three different gestures ('mid air touch', 'mid air punch' and 'mid air grasp'). Again the EMS and the vibration device were attached to the participants' dominant arm (Figure 1). We used two well-known metaphors as stimuli for representing material characteristics (i.e., a stone for hard and a sponge for soft material). We used level 5 and 8 for EMS and for vibation level 2 and 6 as feedback intensity, based on the findings from the prior study. We showed each participant an interaction object and an interaction technique on the screen and asked them to perform the gesture for the object (e.g., grasp a stone). The participant was asked to perform the technique like they would interact with a real physical object. For example, for the 'mid air touch' participants were supposed to perform a full hand touch gesture in the air in the same manner as touching a physical stone or sponge in front of them.

The study is designed as a within-subject study, thus, each participant performs all conditions with both haptic feedback methods. All conditions are grouped by interaction technique and interactive object. The order of all combiantions of materials and gestures are permuted with a latin-square. For each material and gesture each user got all feedback conditions in all possible permutations in a counterblanced order.

In each group, the participants perceived haptic feedback with high and low intensity using the EMS and vibration feedback, again, in a counterbalanced order. We placed the participants $1.20\,m$ standing in front the display, so the participants could not reach the display. The Kinect was placed directly in front of the display. The user was asked to test the gestures first, then the four feedback modalities, and afterwards both together. We advised participants that the point of feedback and the gesture movement should fit together. When the users where comfortable with the feedback signal and gestures we started the study. The tail phase was up to 3 minutes. As shown in Figure 1 the material was displayed on the screen and the user was asked to perform the gesture, in the direction of the visual object. When the user lifted up the arm they received the haptic feedback on the lifted arm. After performing the gesture users were asked to rate the fitting of the feedback for the interaction and the material on a 5-point Likert scale (1=not fitting at all, 5=perfect fit). After 24 trails the users were asked to complete a final questionnaire. After that we conducted semi-structured interviews.

Results

The 20 participants performed all 24 conditions and perceived the EMS feedback 1173 ($M = 58.65$, $SD = 19.23$) and the vibration feedback 860 ($M = 43.00$, $SD = 10.43$) times.

From the questionnaire we found that eight of the participants had experience with free-hand interaction as they previously used the Microsoft Kinect. All of them use vibration feedback on their mobile phones and 70% use force-feedback on gaming console. Furthermore, they agree that force feedback makes the interaction with virtual objects more intuitive ($Mdn = 2$, $MAD = 0$ – 5 Point Likert scale, 1 very good to 5 very bad). Only one participant, had reservations against the use of EMS.

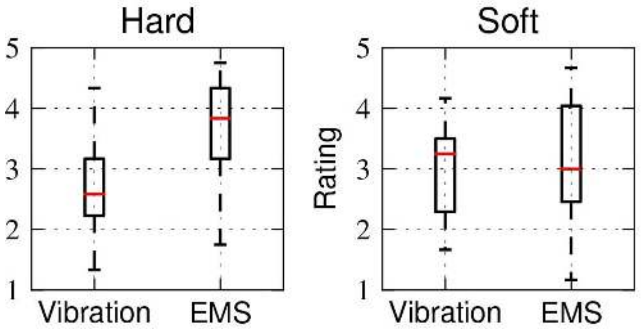

Figure 4: Comparison of EMS and vibration feedback for (left) hard and (right) soft material.

All users are able to distinguish the EMS and vibration feedback. We asked them how well they can differentiate between the low and the strong feedback (5 Point Likert scale, 1=very well, 5=not at all). For both devices, the ratings are high, EMS performing slightly better ($Mdn = 1$, $MAD = 0$) compared to vibration ($Mdn = 1.5$, $MAD = 0.5$). Furthermore, we asked the participants whether they experienced any delay in the feedback (5 Point Likert scale, 1=no delay at all, 5=long delay). For EMS, the average score for the delay is $Mdn = 2$ ($MAD = 1$), for vibration it is $Mdn = 3$ ($MAD = 1$).

The participants rate EMS feedback better than vibration feedback (aggregated over all feedback strengths, interaction techniques, and interaction objects). For comparing hard and soft material we aggregated all gestures and strengths. As shown in Figure 4 (left), EMS is perceived better than vibration for interacting with hard material. A Wilcoxon signed-rank test shows that this difference is statistically significant, $Z = -2.931$, $p = .003$. The comparison of EMS and vibration for soft material (Figure 4, right) is not significant.

Qualitative Feedback

Semi-structured interviews with the participants after the study revealed that they can imagine to use EMS feedback for visual feedback on interaction with a wide variety of materials, including not only hard and soft material, but also cold and pointed material.

Furthermore, they envisioned several application areas. For example, when controlling robots remotely, EMS can provide information about when an obstacle is hit. It can also tell the user how much power is needed to lift a target to make this remote interaction more realistic. Furthermore, participants suggest to use our approach for assistive systems. For example, EMS could be used when an athlete and a trainer are not collocated to provide feedback on whether or not a movement is correctly executed. Feedback could even go so far as to address a particular muscle. They also think about using the feedback in interactive games and for physiotherapy.

Limitations

We acknowledge the following limitations of the study. The perceived feedback strength of EMS depends on the skin resistance and the user's sensibility. Therefore, we had to divide the feedback in high and low in the second study. However, we think of EMS systems as personal devices that only require a one time calibration or can control the feedback current more accurate. In the future, we plan to test the system in different situations and in the wild to increase the ecologic validity. In semi-structured interviews participants report that the direction of movement was more like a magnet than a resistance. Other participants did not notices the direction of the muscle movement.

EXPERIENCE WITH HAPTIC FEEDBACK

Our analysis of the design space shows that a variety of different dimensions needs to be taken into account when providing haptic feedback. First, an appropriate feedback technology needs to be chosen. The results from our study show not only that participants liked EMS feedback, but that they also considered it to provide more realistic feedback when interacting with virtual objects having different properties (hard, cold). The findings suggest that EMS is a particularly well suited technology to provide haptic feedback. This is also backed by the fact that the power required for this method is rather low and we envision that due to its form factor it can be easily integrated in small artefacts or cloths in the near future.

Another property of EMS that should be explored in the future is its ability to preserve the user's privacy. Compared to vibration, it is impossible for others to see or hear EMS feedback. As a result, we envision future security-critical applications, such as ATMs, to employ EMS. An authentication application could, for example, provide a number of haptic authentication patterns, where users need to press a button as they feel their personal pattern. Such an approach would make popular attacks, such as shoulder surfing, impossible.

CONCLUSION AND FUTURE WORK

The use of EMS feedback is still in its infancy. Still we believe that in certain cases EMS can be superior to current haptic feedback methods. In this work, we took a first step towards understanding the potential of EMS feedback. We explored the design space for haptic feedback and then compared EMS to the currently most popular technique, that is vibration feedback.

In two user studies we compared EMS and vibration feedback. First, to calibrate feedback strength, we asked people to rate the similarity of both methods. The results, second, allowed EMS and vibration feedback to be compared with regard to its appropriateness as users interact with objects having different properties and using different gestures. We found that EMS is perceived superior in particular conditions, such as reflecting interaction with hard material.

These results show that it is worthwhile to further explore the design space with the ultimate goal to make free-hand interaction more realistic and natural. We mainly see potential in investigating the impact of different patterns, including patterns of varying impulse lengths, increasing strength, rhythmical impulses, and different shapes of the signal. Furthermore, a combination of different haptic feedback methods, such as EMS and vibration, may be promising.

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