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Magnet-based Around Device Interaction for Playful Music Composition and Gaming

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Abstract

Around Device Interaction (ADI) has expanded the interaction space on mobile devices to allow 3D gesture interaction around the device. In this paper, we look specifically at magnet-based ADI and its applied use in a playful, music-related context. Using three musical applications developed under the magnet-based ADI paradigm (Air Disc-Jockey, Air Guitar, Air GuitaRhythm), we investigate whether the magnet-based ADI paradigm can be effectively used to support playful music composition and gaming on mobile devices. Based on results from a controlled user study (usability and user experience questionnaire responses, users' direct feedback, and video observations), we 1) showed how magnet-based ADI can be effectively used to create natural, playful and creative mobile music interactions amongst both musically-trained and non-musically trained users and 2) distilled magnet-based ADI design considerations to optimize playful and creative music interactions in today's smartphones.

Keywords: Around device interaction, Magnets, Music, Gaming

Introduction

The recent advent of Around Device Interaction (ADI) (Butler et al., 2008) has expanded the interaction space on mobile devices to allow 3D motion gesture interaction around the device, with opportunities for playful music composition and gaming only now taking shape. Using sensors embedded in mobile devices (e.g., (magnetic) compass (Ketabdar et al., 2010), IR distance sensors (Kratz & Rohs, 2009), users can now take advantage of the extra interaction space that their mobile device affords, for leisure and entertainment (Davenport et al., 1998).

ADI can be useful for small tangible/wearable mobile or controller devices (e.g., mobile phones or wrist watches) (Ketabdar et al., 2010). In such devices, it is extremely difficult to operate small buttons and touch screens. By expanding the interaction space around the device, ADI can aid the user in such cases, alongside situations when the device screen is not in line of the user's sight. The ADI paradigm can allow coarse movement-based gestures made in the 3D space around the device to be used for sending different interaction commands such as controlling a portable music player (changing sound volume or music track), zooming, rotation, etc. For mobile phones, it can be also used for dealing with incoming calls (e.g., accepting or rejecting a call). However, ADI need not be limited to use-cases comprising user situational impairments (Ashbrook et al., 2011) or substituting for basic touchscreen tasks (Baudisch & Chu, 2009), but can complement touchscreen interactions with 3D gestures to allow natural, playful interactions in music composition (Ketabdar et al., 2012, 2011) and gaming.

Magnet-based ADI is a novel interaction technique for mobile devices allowing gestural interaction in the whole 3D space around the device[1]. Here, moving a properly shaped magnetic material in hand (e.g. bar shaped, pen, ring) is used to influence the internally embedded compass (magnetometer) sensor in mobile devices by different 3D gestures, hence allowing for touchless interaction around the device. Since the interaction here is based on magnetic fields (which can pass through the hand or clothes, and not depending on users' line of sight), the space at the back and side of device can also be efficiently used for interaction. This technique does not require extra sensors on current smartphones. For these smartphones, it is only necessary to have a properly shaped magnet as an extra accessory. While this can be seen as a limitation of such systems, as will be shown later the use of a magnet allows for a more natural interaction with music related apps.

In this paper, we look closely at how magnet-based ADI can be used in a playful context, to facilitate natural interaction for music composition and gaming amongst both musically-trained and non-musically trained users. Using three musical applications developed under the ADI paradigm (Air Disc-Jockey, Air Guitar, Air GuitaRhythm), we investigate the potential of ADI for playful interaction, in order to gain insight into the acceptability and naturalness of ADI by users who wish to casually engage in playful mobile music composition. Under this investigation, our primary goal is to explore novel methods using mobile technology to entertain users. The rest of the paper is structured as follows: first we provide a review of related work, followed by our research questions and our magnet-based ADI framework. We then present our study design and methods, give our results and discuss them, and finally hint at future work and conclude.

Related Work

Around Device Interaction

Several approaches to ADI have been proposed, which focus mainly on solving the occlusion problem (where the user's fingers cover the touch display during interaction). Baudisch and Chu (2009) show the effectiveness of a pointing input method for very small devices (down to 1" display size), where they use a touchscreen on the back of a device to handle occlusion. Butler et al. (2008) use infrared (IR) sensors on the edges of small mobile devices that allow capturing multitouch gestures around the device, specifically on either side of the long-edge of the device. Relatedly, Kratz and Rohs (2009) use six IR distance sensors to allow coarse movement-based hand gestures, in addition to static position-based gestures, which were also shown to be effective to solving the occlusion problem on small mobile devices. Recently, Kratz et al. (2012) demonstrated using depth imaging cameras to allow for back-of and side-of mobile device interaction, specifically focusing on tracking and recognizing gestures in a virtual object rotation task.

Closely related to the present work, Han et al. (2009) tracked a finger-mounted magnet for handwriting input. Relatedly, Harrison and Hudson (2009) used a magnet attached to the user's finger to allow radial and 2D input for a watch device. Ashbrook et al.

[1] http://www.youtube.com/watch?v=WrVIO-0ak44 (last retrieved: 13-05-2013). Promotional video that illustrates the magnet-based ADI concept in music-related applications.

(2011) also used a magnetically-tracked finger ring, and showed its effectiveness for sighted and eyes-free use for a pointing target-selection task where users could select from up to 8 targets on a menu display. Finally, Ketabdar et al. (2010) also demonstrated that tracking a magnet in the space around the device could allow high gesture classification accuracy for coarse gestures performed by users around the device.

Using 3D Gestures in HCI

There is a recent trend in Human-Computer Interaction to provide what are called Natural User Interfaces (NUIs) (Jain et al., 2011). As stated by Jain et al., (2011), this class of interfaces enables users to interact with computers in the way we interact with the world. An important element of such natural interaction is the use of 3D gestures. However gestures alone do not suffice to allow seamless natural interaction, as the user still needs to receive feedback from the system on a performed gesture (Norman, 2010). This is usually complemented by the use of touchscreen buttons, menus, auditory or speech feedback, or some kind of visual feedback from the system. Nevertheless, in allowing the use of 3D gestures for activities such as music composition (e.g., guitar strumming), the primary interaction with a system can be seen as largely natural.

Recently, Grandhi et al. (2011) investigated the naturalness and intuitiveness of gestures, where the goal was to understand how users' mental models are aligned to certain gestures. Relevant finding here is that tasks that suggest the use of a tool should have gestures that pantomime the actual action with the imagined tool in hand. This points to the importance of tool use in gestural interaction where appropriate. Kühnel et al. (2011) investigated a user-defined gesture set for gesture-based interaction with smart-home systems (e.g., opening and closing the blinds), which highlighted the merits of this natural interaction method for daily activities in the home. Another line of research by Rico and Brewster (2010) focused on the social acceptability of produced gestures under different settings (e.g., at home, at the pub, etc.), where they also found that some gestural interactions were perceived by users to be enjoyable. The goal of their work was to equip gesture designers with knowledge of which gestures are socially appropriate under which settings and situations. Together, the foregoing studies demonstrate the growing use of 3D gestures as an intuitive and natural interaction alternative to mobile touchscreen interactions, which is generally perceived to be socially acceptable.

Gestural Interfaces for Music Interaction

The earliest example of a gesture-based music instrument is the Theremin (Theremin, 1996), which used electronic field sensing of hand positions in space to allow music composition. Since then, there has been a range of digital music instruments that use IR distance (e.g., Airstick free-gesture music controller (Franco, 2005) or vision sensing that go beyond keyboard interactions and allow bodily gesture-based interactions). Related to the present work, Gillian et al. (2009) proposed a gesture-based musical DJ game that uses the mobile device's 3-axis accelerometer and touchscreen interactions where users have to scratch at a specified musical beat (when cued by different multimodal feedback).

Kayali et al. (2008) developed three tangible mobile interfaces as gestural instruments, one of which is relevant here is a simplified guitar prototype that allows strumming frets using the Nintendo DS stylus. Gillian and Paradiso (2012) demonstrated how 3D depth sensors can be used for discrete and continuous control of a gesturally controlled music instrument. While these presented examples exemplify the use of gestural interaction for controlling virtual music instruments, the interaction techniques offered use motion sensors that require moving the device itself, which risks users losing concentration on the task at hand. In our case, we use the motion of the hand, rather than the device, which affords more natural interaction and allows the phone display to be used more efficiently when composing music. Recently, Ketabdar et al. (2012, 2011) presented a demonstration of a guitar application that also uses magnet-based ADI to allow in air strumming, however their work was more focused on the technical infrastructure behind the guitar app, and therefore lacked any user evaluation. We add to the body of work presented there, by presenting two additional apps (Air DJ and Air GuitaRythm), with a focus on evaluating the apps from a user-centered standpoint.

Evaluating Playful Interactions

A playful interaction experience, when understood as a process, is characterized by amusement, risk, challenge, flow, tension, and/or negative affect (Nacke et al., 2009; Csikszentmihalyi, 1990). Finding an appropriate methodology to measure and understand playful experiences provides a challenge, given the diversity of playful interactions across users and within a single user. This challenge is additionally amplified by the difficulty in probing into the inner subjectivity of the cognitive and emotional lives of people. Attempts at providing quantitative and qualitative metrics of game experiences have already been taken in (Nacke et al., 2009), where they used biomarkers (EEG recordings, EMG recordings, etc.), behavioral indicators (button pressure responses, human postural and gait measures), and the Game Experience Questionnaire (GEQ) to measure gaming experiences. However, in our case we are not dealing with console or desktop games, and so such metrics are not very useful to characterize user entertainment with our mobile music-related apps (especially in later testing stages where we expect users to be on the move).

Instead, we make use of questionnaires to measure users' experience with interactive systems and the perceived usability of the apps. To do this, we follow the approach by Lucero et al. (2011) by using the AttrakDiff2™ (Hassenzahl et al., 2003) questionnaire to evaluate playful aspects of interactive systems. Additionally, we use the System Usability Scale (Brooke, 1996) questionnaire, as it is a robust, industry standard in quickly evaluating a system's usability. Both of these scales are discussed under Section Study Design. Importantly, for the early stage of our prototype apps, we make use of qualitative observations and interviews, in order to gain insight from users directly on improving our apps and the interaction methods they support. In this case, looking at usability from a performance standpoint (cf., Gajadhar et al., 2010) (e.g., high scores, touchscreen presses, or magnetic signal deformations) would not be useful for understanding how users deal with this new interaction method for music composition and gaming.

Research Questions

Given previous work on ADI, gesture-based interaction, and music composition, our main research question is: *how can (magnet-based) ADI be used to support playful music composition and gaming on smartphones?* Specifically, we investigate usability and user experience[2] issues, and user acceptance of the ADI paradigm to support playful and creative interactions (Davenport et al., 1998), using three mobile music-related high-fidelity prototype apps (Air Disc-Jockey, Air Guitar, Air GuitaRhythm) that allow natural interaction (Grandhi et al., 2011) using a magnet. By allowing natural (cf., Grandhi et al., 2011; Kühnel et al., 2011) and in some cases enjoyable (cf., Rico and Brewster, 2010) gesture-based interaction with mobile devices, our hypothesis is that the ADI paradigm would be perceived as a fun and natural means of mobile interaction, in the context of playful gaming and music composition.

Two of the developed prototype apps (Air DJ, Air Guitar) allow free creative expression in composing music, and the last designed as a music game (Air GuitaRhythm). Our target user group is casual gamers and users who wish to compose music nonprofessionally, as part of everyday playful interactions with mobile devices. However, since two of the prototype apps developed lend themselves to creative music composition, testing users with previous musical training was required to provide insights on whether the ADI concept is perceived differently by those who can and those who cannot compose music. Given this distinction, we expected that users who were musically trained would perceive the creative music apps (Air DJ, Air Guitar) more favorably than those who did not have such training, whereas all user groups should perceive the gaming app similarly. This is because the musical game, which is easy to learn and play with a challenging score-based system, is easily accessible by all user groups. By contrast, the musical applications could perhaps be seen as having a higher barrier of accessibility if a user lacks the necessary music skills to compose music.

Investigating usability, user experience and acceptance afforded by the three magnet-based ADI musical prototype apps here yields two main research contributions: first, it provides a user-driven concept validation of whether the ADI paradigm, in allowing natural gestural interaction around mobile devices, can support use-cases for playful and creative music interaction (Section *Supporting Playful Music Composition and Gaming*.) Second, it equips future interaction designers wishing to make use of magnet-based ADI with design considerations when designing playful and creative mobile ADI interactions (Section *Design Considerations for Applied Magnet-based ADI*). Additionally, we provide initial results on the social acceptability of ADI when interactions take place in public settings, as well as additional use-cases participants reported on.

Magnet-based ADI

Framework

A piece of magnet when moved close enough to a smartphone can influence the compass sensor. The temporal pattern of such an influence is registered by the compass sensor, and can be interpreted as a gestural command using appropriate machine learning algorithms. Getting useful information from the magnetic sensor is not only algorithmically simpler than implementing computer vision techniques, but this approach also does not suffer from illumination variation and occlusion problems. In other words, it does not require direct line of sight into the camera, which enables

[2] UX here is based on ISO 9241-210 (ISO, 1994) definition: "A person's perceptions and responses that result from the use or anticipated use of a product, system or service."

covering the whole 360˚ space around the device for interaction.

The output of the compass sensor consists of 3 signals showing the strength and direction of the magnetic field along x, y and z directions. Each sensor reading composes a vector of 3 elements, where a gesture is presented by a certain pattern in a sequence of these vectors. A time derivative function is applied to sensor readings in order to highlight changes in the pattern of magnetic field, and remove effects of earth's magnetic field (which is almost constant). The sequence of vectors is divided into overlapping windows for gesture recognition. Depending on the type of gesture, different techniques can be applied for interpreting sensor readings as a gesture class. In our case, we used heuristic decision rules and Multi-Layer Perceptrons (MLPs) (Minsky & Papert, 1969), which for our framework have been shown to achieve gesture recognition accuracy of 83.7% and 91.4%, respectively (Ketabdar et al., 2010).

For simple gestures, such as detecting only a triggering action as in the case of our apps below, average norm of vectors inside a window is compared with a predefined or adjustable threshold. Adjusting the sensor can affect the sensitivity for the triggering action. A triggering action involves a rapid motion of hand (with magnet) that causes rapid changes in the pattern of magnetic field around the device, resulting in a significant change in magnetic signal norm for a limited period of time. Motion of the device itself can also cause changes in the compass sensor output, due to displacement of the sensor with respect to earth's magnetic field. Rapid motion of the device is detected based on embedded accelerometer readings, which allows stopping gesture execution. For recognizing more complicated gestures, the sequence of sensor readings is compared with a pre-recorded sequences using template matching techniques such as Dynamic Time Warping (Sakoe & Chiba, 1978). However since here we deal with simple gestures, heuristic decision rules suffice.

Application Design Process

All the applications were implemented on the Apple iPhone 4® as functional interactive prototypes. Two of the applications described below (Air DJ and Air GuitaRhythm) followed a user-centered design process, where interfaces underwent a round of design iterations thereafter. For these apps, qualitative focus group (user insight) sessions were conducted. There were 5 focus group sessions with 10 participants (5 male, 5 female) aged between 20-30, where half had a background in music, and the rest in design. Sessions were carried out in a collaborative setting (2 participants per session). The collaborative dual-testing of participants (who did not know each other beforehand) was conducted as such to ensure discussion in an interactive manner amongst participants on how to improve the apps. Measures included semistructured interviews, think aloud protocols, and observations as protocoled by two observers.

Participants found the concept of magnet-based interaction behind Air DJ and Air GuitaRhythm very appealing, where main feedback involved usability issues (especially the navigation model in GuitaRythm) model and interface redesign suggestions (icon redesign, GUI element reordering, more transparent labels). Participants were also quite positive about using magnets for playful ADI interaction, and were willing to pay for a good magnet to ensure smooth interaction with the apps. However they explicitly stated that they should be readily available in stores and come in different form factors. These earlier findings have been incorporated into the design of the apps described below.

Prototype Applications

Air Disc-Jockey

Air DJ combines standard functionalities usually found in different electronic music instruments. These comprise playback of a song from the users music library, real time control of a lowpass filter applied to the playback, triggering of drum and effect samples and real time synthesis of sounds based on the user's hand movements. The Air DJ interface is shown in Fig. 1. A tutorial including an audio/video demonstration of the app can be found by tapping the question mark (6). A song (from iTunes® library) is loaded into the application by pressing the plus icon (7) on the note symbol, and thereafter transcoded to a pcm file. After the transcoding process, playback is started by pressing the Play/Pause button (1). Song title (2) and play progress time (8) are shown inside the music player area. The progress bar (3) indicates the current playback position with respect to the total length of the song. Tapping the bar allows the user to jump to a certain song position according to the tap location. In Settings (11), the user can adjust the music volume and magnetic sensitivity. For activating drums and effects, real-time audio synthesis, and real time control of a lowpass filter, the user has to press and hold (5) the corresponding touchscreen button(s).

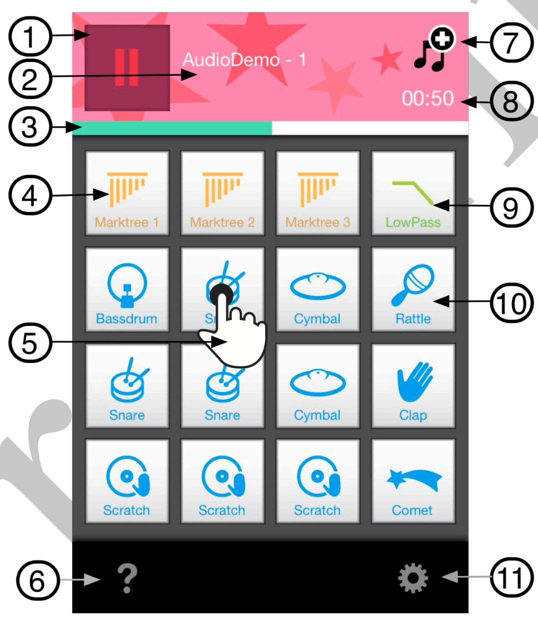

Figure 1: Air DJ interface. See text for explanation of labels.

Air DJ allows transforming the user's hand motion to sound using real time audio synthesis. Sound is only generated when the user is actually moving the magnet in the vicinity of the device. Movement is detected from the change of the absolute value of the total magnetic field strength. A total of 3 synthesizer units (4) are available, named Marktree (1, 2, 3), which are activated by pressing the corresponding button. When the magnet is moving, Marktree 1 generates short random frequency sinusoids, which sum up to a kind of a metallic sound. MarkTree 2 and 3 in contrast generate frequencies corresponding to the notes of two harmonically related minor seven chords (Dmin7, Amin7). During playback of a song, if the LowPass filter (9) is activated, it attenuates high frequencies according to the total strength of the magnetic field. The filter center frequency decreases with decreasing distance between the magnet and the mobile device, hence high frequencies are attenuated stronger when the magnet is close to the device. Air DJ also enables the user to play multiple high quality drum samples (e.g., Snare, Cymbal, Clap) along with the music using hand motion. The drum samples are triggered by pressing one of the blue sample buttons (10) and simultaneously moving the magnet near the mobile device. Main motivation for including these audio synths and effects was that they were determined to be suitable for the magnetic technology used. With respect to the choice of sounds (e.g., MarkTree), these are common sounds that were also deemed suitable as they go well with natural background noise. Furthermore, these audio synths and effects were included as participants from the earlier pilot studies enjoyed playing with them.

Air Guitar

Air Guitar allows playing guitar songs (which are simple lists of chords) by pressing and holding (at least) one fret on a virtual guitar neck while triggering with a magnet. Chords are built from individual guitar samples, where samples cover the visible note range (MIDI: 40...69). The Air Guitar interface is shown in Fig. 2. At the time of

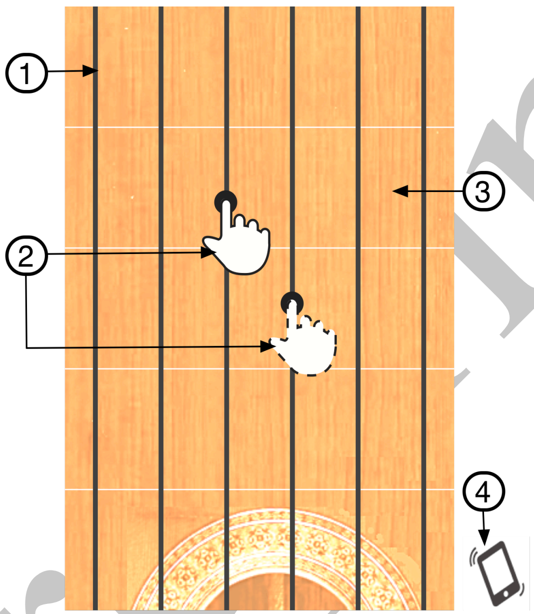

Figure 2: Air Guitar interface. See text for explanation of labels.

testing, Air Guitar was still in its early stages and hence the interface and features were still basic (e.g., played songs cannot be saved or shared). The application starts with a virtual guitar neck with six strings (1) and five (I...V) frets (3). The user can play a chord while placing his finger(s) on one or more notes (2) and moving the magnet with the other hand. Open strings (from left to right) correspond to MIDI notes: 40 (E-String), 45 (A-String), 50 (D), 55 (G), 59 (B), 64 (E). The corresponding sample of a selected note is determined using the fret number (I...V), where Sample Number = $MIDI_{OpenString}$ + Fret Number. At this stage of development, the Air Guitar app does not support playing open strings. Currently, to get to the settings page where the volume and magnetic sensitivity can be adjusted, the user has to shake the device (4).

Air GuitaRhythm

Air GuitaRhythm introduces an innovative concept for playing music reaction games in the style of Guitar Hero® and Rock Band® on mobile devices using magnet-based touchless 3D gestures. Air GuitaRhythm allows the user to play the lead guitarist of a virtual rock band. In Air GuitaRhythm, songs are delivered with the app and consist of the mp3 file and text file containing information of the game melody (note event time stamps, MIDI note number). The user can choose a tutorial which includes an audio/video demonstration of the app, or select a song. After having selected a song, the play screen is displayed and a counter starts counting backwards from 3 to 1, where then the song playback starts. The Air GuitaRhythm interface is shown in Fig. 3. A magnet in hand allows the user to use natural hand gestures similar to real guitar playing to play the notes of the main guitar melody of a song. MagiGuitar challenges the user to move the magnet rhythmically correct (on the dashed line (5)) according to a note pattern shown on the display. Song progress bar (1) and song title (4) are displayed above the note display area, and the three gray icons (3) at the bottom of the screen allow the user to Stop, Pause, or Restart the game. In Settings (10), the user can adjust the music volume and magnetic sensitivity.

After song playback has started, note symbols (6) start moving across the screen from left to right representing notes of the game melody. The user has to move the magnet in the vicinity of the phone to play a note of the melody. Notes can only be played as long as they are in the Play Zone (7). The perfect moment to play a note is when it is aligned with the dashed line (5) of play zone resulting in nice sounding

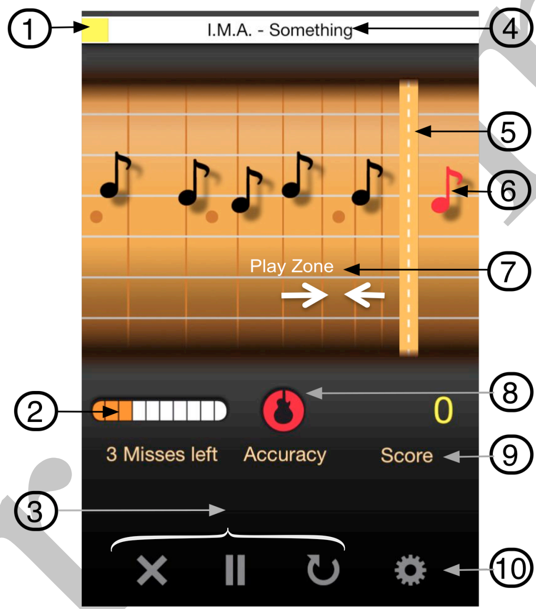

Figure 3: Air GuitaRhythm interface. See text for explanation of labels.

melodies. The user is supposed to move the magnet only if there is a note in the zone. Otherwise an error sound chimes when the score (9) gets lowered. Notes that have been triggered correctly will be displayed in green, and those missed will be displayed in red (as shown). With every missed note, the life bar (2) decreases by one element. Game ends when there are 0 misses left. Triggering a note correctly refills the life bar by one element. Each note that is triggered correctly will increase the score Accuracy (8) (percentage of correctly triggered notes), which indicates how many notes were triggered correctly. The Accuracy score is green when most notes are triggered correctly, and red (as shown) when hardly any notes have been triggered correctly. At the end of a song, the performance of the user is evaluated and compared to the current high-scores of the corresponding song. If the user's score is higher than one of the scores found, the user can add his name to the high-score table.

Methods

Study Design

To investigate the potential of magnet-based ADI for music composition and gaming, we designed a controlled study to test both the usability and user experience of our mobile music apps. A controlled laboratory study was suitable in this case as it allows drawing rich user insights and concept validation without the unpredictability of in-the-wild testing. While Air DJ and Air GuitaRhythm were high-fidelity prototypes, Air Guitar was still in its early stages. It was nevertheless included in our study as it provided high potential for musical creativity. Together, the applications served as probes into getting users acquainted with the paradigm of magnet-based ADI in general, and for applications to music composition and gaming in particular.

Since only Air GuitaRhythm was a fully developed game (i.e., with a performance scoring system), we expected it to appeal more to the general population of users. The DJ application and the Air Guitar on the other hand, were expected to appeal more to users with at least some musical training. We defined a musically trained participant as a person who plays at least one musical instrument, and has at least 2 years of experience playing it. To deal with the difference in target groups, we tested users who do not have any musical training and users that do. This we hypothesized would provide greater insight into the use of magnet-based ADI for both creative composition (by musically trained users) and for general entertainment and enjoyability (by non- musically trained users).

Figure 4: Ring magnet (left) and bar magnet (right).

The foregoing design decisions led to a controlled led to a controlled study with a mixed between and within- subject factorial (2 x 3 x 2) design. There were three independent variables (IVs): music training (2 levels: music training vs. no music training), magnet-based ADI application (3 levels: Air DJ vs. Air Guitar vs. Air GuitaRhythm), and magnet (2 levels: bar-shaped vs. ring magnet). Music training was a between-subjects factor, and ADI application and magnet were within-subjects factors. Each between-subject condition tested all applications and both magnets, counterbalanced and randomized across participants. Participants were given a tutorial on how to use the magnets to interact with each application, and they were allowed to spend as much time as they wanted on each application. To avoid experimental artifacts associated with the form factor of the magnets, participants were asked to play with two different magnets: a bar-shaped magnet (~5cm length, ~0.5cm width) and a ring-shaped magnet (~3cm diameter, ~0.8 cm width), both shown in Fig. 4. The ring-shaped magnet had stronger magnetic force due to its thickness. These were calibrated accordingly for use with each app, where users could additionally calibrate the sensitivity if desired. Additionally, testing two different magnets also served as a probe to get participants to imagine later the form factor possibilities for magnet-based ADI. While all users were asked to use both magnets, the usage duration for each were not explicit conditions for this study, so as not to artificially constrain the study setup too much. As mentioned, the use of two magnets was provided primarily to allow users to reflect on the possible form factors that magnets come in, where finally we expect that many shapes and sizes of magnets would be available commercially or at home for users to use.

To measure the usability and user experience (our dependent variables) of each musical app, five data sources were collected: a) AttrakDiff2 questionnaire[3] responses b) System Usability Scale (SUS) (Brooke, 1996) responses c) Likert-scale questions about participants' attitudes toward magnet-based ADI and the given prototype apps tested d) video recordings of participants' gestures, and e) post-experiment interviews, to get direct user feedback on magnet-based ADI.

AttrakDiff2 (Section *Appendix A*) measures pragmatic and hedonic qualities of interactive systems by allowing participants to provide ratings on a 7-point semantic differential scale (range [-3, 3]) for 28 attributes, resulting in 4 quality dimensions: 1) Pragmatic Quality (PQ), which measures usability of a product (or in our case each application). Here, PQ gives insight into how easy and straightforward it was to use each application 2) Hedonic Quality - Identification (HQ-I), which gives insight into the extent that users can identify with each application 3) Hedonic Quality - Stimulation (HQ-S), which gives insight into the extent that each application stimulates users with novelty 4) Attractiveness (ATT), which provides a global appeal value and quality perception of each application.

Despite that the applications were all prototypes, we nevertheless decided to additionally administer the SUS (10-item questionnaire on a 5-point Likert scale) to gain additional insight (aside from the PQ category in AttrakDiff2) into the ease of use, efficiency, and satisfaction of each application (Section *Appendix B*). The SUS has been shown to be a robust and reliable standalone tool for measuring perceived usability of interactive systems, where a score of 70 and above indicates an acceptable score (Bangor et al., 2008). While there is some overlap between the SUS and AttrakDiff2, collecting multiple sources of data provides stronger evidence of findings. Additionally, usability is only one dimension of AttrakDiff2 (which is more focused on UX issues of enjoyment and novelty).

Likert-scale questions (4-item; $\alpha = .71$) we gave participants asked about their first impression of the apps, how comfortable it was to play with each app, how easy to learn using each app, and whether or not they enjoyed making music with each app. An additional item asked whether or not they would be willing to carry a magnet around (Section *Appendix C*). Additionally, we had a semi-structured interview (Section *Appendix D*) at the end of each testing session, where users could give their feedback directly on what they thought about ADI using magnets, their expectations about availability of magnets when they download these apps, as well as their preferences for the magnet form factor (shape, size, color). Additionally, they were asked about other application use-cases that could potentially benefit from the magnet-based ADI paradigm. To gain insight into whether this mode of interaction is socially

[3] AttrakDiff2™ is a questionnaire originally developed to measure the perceived attractiveness of interactive products based on hedonic and pragmatic qualities (Hassenzahl et al., 2003).

acceptable, they were asked whether or not they would interact with mobile phones using magnets in public places (e.g., in the metro, bus, or on a public street).

Participants

24 participants (15 male, 9 female) aged between 23-39 (M_{age}= 27.2; SD_{age}= 4.1) were recruited. Half had musical training, and the other half no musical training. This was identified through the recruiting process and later through the information forms participants had to fill in before each test session. Our participant sample spanned 13 different nationalities, where all were right-handed. No left-handed participants were tested as this was not an explicit aspect of our research questions. Half (12/24) had a technical background, and nearly half (11/24) were familiar with gaming consoles that use some form of gesture recognition technology (e.g., Nintendo Wii© or Microsoft Kinect©). Most of the musically trained participants played the guitar (9/12) among other instruments (piano or accordion), with the rest having been trained to play only the piano (3/12).

Setup & Procedure

The study was carried out at the usability lab at Telekom Innovation Laboratories. Each experimental session took between 1-1.5 hours. Participants were tested in pairs, and provided each with an iPhone 4 with the prototype apps, as well as two magnets (bar- and ring-shaped). Study participants were guided by two experimenters. They were seated at opposite ends of a table, where a tripod-mounted camera was aimed at their gesture interaction space. They were allowed to define their own interaction space (within the camera angle's view) to ensure their comfort during the session. At start of the session, each participant filled a background information form, signed an informed consent form, and read through instructions for performing the task. Before each condition, they were given a quick tutorial and demo on how to play with each app.

After the tutorial, participants would then play with each app (with no set time limit). They were asked to try out both magnets. After stopping each application, they were asked to fill in the AttrakDiff2, the SUS, and the constructed Likert-scale intermediate questionnaire. All participant responses were set on the same questionnaire, to ensure that responses were relative to one another. After playing with all apps, they were briefly interviewed about their experiences (~10 min.) of the experimental session and the magnet-based ADI paradigm and given applications. Afterward, they were thanked for participating, signed a receipt form, and offered a monetary reward for participating (which participants knew they would get).

Results

Perceived Usability & User Experience

AttrakDiff2 Responses

We ran an independent one-way ANOVA (with all assumptions satisfied) between groups (musically trained vs. non-musically trained) for each AttrakDiff2 dimension (PQ, HQ-I, HQ-S, ATT), however no significant differences between groups were found. Therefore, both groups were treated as a uniform sample. We ran a repeated measures ANOVA comparing mean AttrakDiff2 responses across all participants on each dimension for each of the tested apps (Air DJ, Air Guitar, Air GuitaRhythm). Results showed significant differences in responses across quality dimensions for only PQ, HQ-I, and ATT. Post-hoc pairwise comparisons (with Bonferroni correction[4]) between each app (Air DJ, Air Guitar, Air GuitaRhythm) were conducted in every case. Results (means, standard deviations, confidence intervals, significance ($\alpha = .05$), and effect size (partial eta-squared values)) for each tested app are shown in Table 1. Where significant, dimensions and app names are represented in bold, and where a particular pairwise comparison is not significant, app names are in (additional) italics.

For the PQ dimension, participants perceived clear differences between the Air DJ and the Air Guitar apps, and between the Air Guitar and Air GuitaRhythm apps, but not between the Air DJ and Air GuitaRhythm apps. Lack of a difference in the latter case is not surprising, given that the Air Guitar app was still in the early stages of development, and usability issues associated with its use were expected (which we discuss below). Scores for both Air DJ and Air GuitaRhythm apps in general showed that the current usability of those prototype apps was satisfactory. For the HQ-I dimension, while results showed an overall significant difference between AttrakDiff2 responses, post-hoc pairwise comparisons were not significant. With the scores for all apps all close to zero, we can draw that our participant sample did not clearly identify with these music-related prototype apps. This could be due to the novelty of magnet-based ADI for playful music composition and gaming, which may take time to be accepted by users as an established alternative mode of mobile interaction.

Dimension	**App**	*M*	*SD*	*CI*	*P*-value	η_p^2
PQ	***DJ***	.7	1	[.2,1]	**p=.001**	.3
	G	-.1	1.1	[-.6,.4]	*F*(2,46) = 8.3	
	GR	1	.9	[.7,1.4]		
HQ-I	DJ	.2	1.1	[-.1,.9]	**p=.02**	.2
	G	-.3	1	[-.8,.1]	*F*(2,46) = 4.2	
	GR	.3	1.2	[-.2,.8]		
HQ-S	DJ	.6	.9	[.2,1]	p=.29	.1
	G	.2	1.2	[-.4,.7]	*F*(2,46) = 1.3	
	GR	.5	1.2	[-.04,1]		
ATT	DJ	.8	1.2	[.3,1.3]	**p=.03**	.1
	G	.1	1.4	[-.5,.7]	*F*(2,46) = 3.9	
	GR	1	1.4	[.5,1.6]		

Table 1: Descriptive and inferential statistics of participant (N =24) responses (range [-3, 3]) on tested apps (DJ: Air DJ, G: Air Guitar, GR: Air GuitaRhythm) for each AttrakDiff2 dimension: PQ = Pragmatic Quality, HQ-I: Hedonic Quality-Identity, HQ-S: Hedonic Quality-Stimulation, ATT: Attractiveness.

For the HQ-S dimension, there were no statistical differences, where average responses were between 0 and 1. Here, we expected responses on HQ-S to be higher, given the highly positive qualitative responses from participants in the exit interview (described below). This could be due to the limited stimulation categories of the

[4] Backward-corrected SPSS© Bonferroni adjusted p-values are reported.

AttrakDiff2 questionnaire, or due to participants hesitant about providing very high ratings in their responses. While this finding may be interpreted with caution, it should nevertheless serve as an indicator that the engagement and stimulation factors associated with interacting with these music-related prototype apps can be improved upon. For the ATT dimension, results showed an overall significant difference, however post-hoc pairwise comparisons did not. Response scores for the Air DJ and Air GuitaRhythm were on or around 1, indicating that both apps generally appealed to participants. For the Air Guitar app, the near-zero response could have been influenced by the poor usability of the app, which may have affected its current attractiveness.

System Usability Scale Responses

Measured SUS responses were calculated according to (Brooke, 1996), and analyzed in terms of average score frequency distributions. Results are shown in Fig. 5. For the Air DJ app, half of participants (12/24) gave an acceptable SUS score (70 or above). For Air Guitar, few participants (4/24) gave an acceptable score, and for Air GuitaRhythm, slightly more than half (15/24) gave an acceptable SUS score. For the Air DJ and Air GuitaRhythm apps, these scores reflect that the ADI-based apps using magnets are nearly ready for entering the consumer market with only few issues remaining (as will be discussed later). For the Air Guitar app, the acceptable usability of the current app was quite low, which is not surprising given the early stage of development during time of testing.

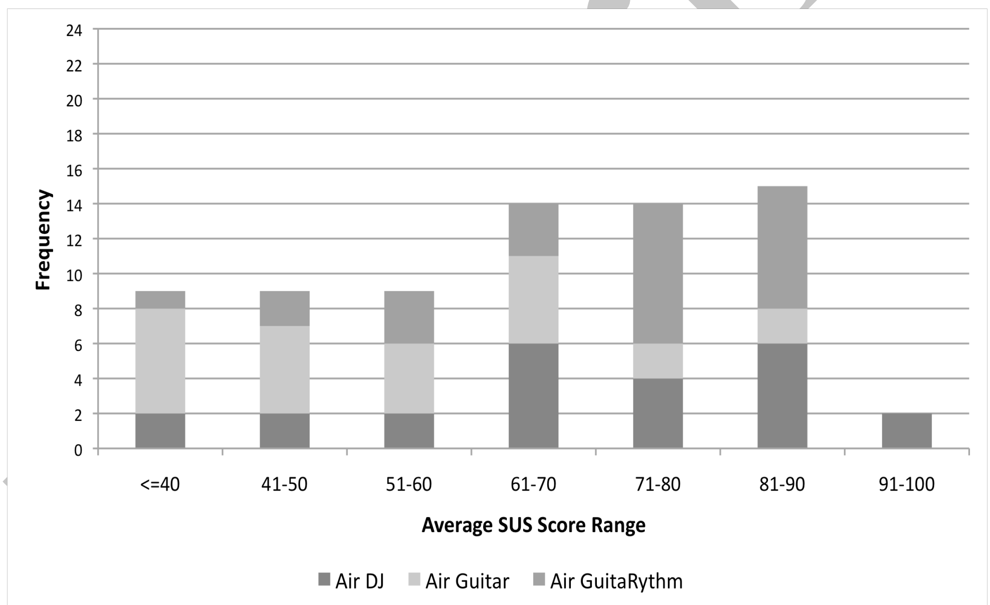

Figure 5: Frequency distribution of mean System Usability Scale responses across participants (N=24) for all tested apps.

Users' Subjective Feedback

After interacting with each of the magnet-based ADI apps, participants were given a 7-point Likert scale (1-strongly disagree, 7-strongly agree) exit questionnaire to gather their overall feedback on each of the tested apps (Medians (Md) and Interquartile Ranges (IQR) are reported). This was followed by a semi-structured interview.

Overall User Acceptance of Magnet-based ADI

For all tested apps, participants reported that they had a positive first impression of interacting with the apps (Air DJ: Md=5, IQR=3-6; Air Guitar: Md=5, IQR=2.8-5; Air GuitaRhythm: Md=5, IQR=4-6). This was confirmed during the interviews, were most participants (20/24) had a positive overall impression of composing music and gaming using magnet-based ADI (P6: *"It was really cool with the magnet, I mean I've never even heard of that before!"*).

While overall responses were positive, some participants had concerns regarding the originality (P12: *"I have a Nintendo Wii, and I've seen similar technology so I was not so impressed."*), the use of magnets (P24: *"Sensitivity of the magnet was not good.. especially the DJ app, I think it's much more practical to tap on the instrument [touchscreen] then using a magnet."*), and the limited features of the prototype apps (P17: *"Some of the apps you can make more music, but some were boring (like the Air Guitar app)... maybe would be cooler if you can make more things with the magnet."*). When participants were asked about their expectations of the availability of magnets, all participants stated (as in early user insight sessions) that magnets should be available at electronic and large department stores (e.g., Apple Store®, Woolworths®). Four participants mentioned that if the apps require a particular shape or strength of a magnet, then such magnets should be readily available for purchase.

All participants found the apps easy to use (Air DJ: Md=6, IQR=4.8-7; Air Guitar: Md=6, IQR=3.8-6; Air GuitaRhythm: Md=6, IQR=5-7). Participants were generally comfortable interacting with the Air DJ (Md=5, IQR=5-6) and Air GuitaRhythm apps (Md=6, IQR=4-6) using a magnet, however were neutral with respect to the Air Guitar app (Md=3, IQR=2-5). When asked about whether they are willing to carry a magnet with them to interact with such apps, few participants (8/24) reported they would. Likewise to the mixed adoption of pen-based computing (Kurtenbach, 2010), this was expected as users do not always want to carry an additional accessory. However, participants that stated they would carry a magnet, mentioned (x5) that attaching the magnet to their keychain or as part of the phone's casing were the easiest methods to carry it around.

Participants (18/24) were generally quite positive about using magnets for such interaction (P11: *"I find the idea itself nice, having the interaction outside in your own personal area around the phone… these small gestures in your personal space feel very natural, it feels good."*). Main issues concerning the interaction included the sensitivity of the detection (P10: *"I thought magnets weren't sensitive enough [especially for Air Guitar App], so that was a bit annoying."*), having to carry the magnet (P14: *"The magnet is small and maybe you can lose it in your pocket."*), and using magnets near electronic devices (P12: *"I was feeling a bit uncomfortable because I think the magnet affects the hard disk, so I was a bit scared."*). The concern of the sensitivity of the magnet can be adjusted accordingly through user-defined calibration. Regarding the possible damage to the smartphone from the magnet, the magnets used for these applications are not strong enough to interfere with the smartphone's hard disk[5].

Magnet Form Factor

[5] However, all magnets pose risks to magnetic strips (e.g., on credit cards) at close range. With the rise of new card readers such as Near-Field Communication (NFC) however, this problem is avoided.

Participants were asked about their preferences for a magnet size or shape for ADI. Around half (13/24) preferred the magnet ring, some (9/24) the bar-shaped magnet, and the remaining (2/24) had other preferences. The ring was preferred due to the ease of carrying it (P3: *"I liked the ring more because you can slip it on and you can have a free hand."*), the natural interaction it affords (P4: *"For the Air Guitar app, a bar makes more sense, but I liked the ring. I thought the ring felt more natural."*), or aesthetic reasons (P13: *"I wouldn't mind wearing a (colorful) ring, as a fashion accessory."*). The strength of the magnetic signal from the ring was perceived to be both good (P18: *"It's [the Ring] stronger and easier to use."*) and bad (P3: *"The ring was stronger and there was many double strokes and I didn't like that."*). Other issue reported with the ring-shaped magnet is whether or not it fit the participant's finger (P16: *"At first I thought I liked the ring better, but then it was a bit awkward to use – it fell off at times. So maybe one that fits me better."*).

The bar-shaped magnet was preferred by some participants because it resembled a stylus/pen, which was easy to grasp. One participant stated that it resembles an instrument, which is suitable for these apps. Two participants mentioned it was smaller (and therefore easier to carry). The main concern over the bar-shaped magnet was that the magnetic signal was weaker, and so lacked sensitivity during music composition and gaming, despite calibration. Some participants (4/24) mentioned that for the Air Guitar app, the magnet should probably be shaped like a guitar pick (P5: *"As long as we're playing guitar, best to be shaped as a guitar pick. More realistic."*). Likewise with a drumming application, where the magnet should be shaped like a drum stick.

Interaction Methods and Styles

Based on our video observations and users' feedback, there arose a number of issues concerning the supported interaction method of interaction using a magnet. First, participants differed in how they held the smartphone during interaction, where some preferred to lay the device on the table, and others held the device in one hand and the magnet in the other. For putting the device on the table, this was the case for the Air Guitar and Air DJ apps, where both touchscreen interactions (holding an instrument button or holding string(s) with fingers) and moving the magnet required simultaneous hand actions (P3: *"It's a good idea to use magnets, but hard to press buttons while holding a magnet and a phone."*). This was especially of concern for the Air Guitar app, as holding both the smartphone and magnet could pose risks in dropping items (P7: *"Air Guitar here is a bit complicated because you have to use more than one finger, to put the device down and use a magnet. And I'm afraid of dropping the phone so I don't hold it."*). These concerns are in line with previous work that investigated the effects of encumbrance (manual multitasking) on mobile interactions like pointing and typing on a keyboard (Oulasvirta & Bergstrom-Lehtovirta, 2011), which may negatively impact task performance.

Another concern was the form factor of the mobile device for playing Air Guitar, where a physical guitar body extension would allow easier grasping of the smartphone as if it were a real guitar (P5: *"Holding the iPhone [for Air Guitar] was kind of uncomfortable, you would need a physical extension."*). Given that the smartphone's display may not always be visible to the user, this brought up the question of whether enabling vibrotactile feedback (Marshall & Wanderley, 2006) (varied by different parameters such as rhythm and waveform) on the strings could better allow for eyes-free air guitar interaction. For the Air DJ app, one participant found it more practical to not gesture altogether using a magnet (P24: *"For the DJ app, I think it's much more* *practical to tap on the instrument [touchscreen] then using a magnet."*). Together, these findings show that using the magnet-based ADI paradigm for everyday playful interactions like music composition and gaming requires further design considerations (effects of encumbrance, form factor, vibrotactile feedback) when merging physical (gesture-based) and digital (touchscreen) interactions.

Playfulness & Professional Music Performance

All participants reported enjoying composing music and playing with the apps (Air DJ: Md=5, IQR=3-5; Air Guitar: Md=4, IQR=2-5; Air GuitaRhythm: Md=5, IQR=3.8-6). When participants were asked to rank their favorite app, Air GuitaRhythm ranked the highest (12x), followed by Air Guitar (7x) and the Air DJ app (5x). Given that Air GuitaRhythm was the only app developed with full gaming elements, it was perceived to be overall the most engaging and fun (P23: "*The first one [Air GuitaRhythm] you had a goal, and it was really fun, but the other two I didn't know what to do."*). This is in line with previous work on flow experiences where challenge (here in the form of a game score) strongly influences fun and engagement (Csikszentmihalyi, 1990). However, amongst those who could play music, the Air Guitar app was perceived to be the most creative of the apps (P13: *"I liked the guitar app because it was very creative."*).

Even though the developed applications were not targeted towards professional musicians, a few participants with musical training expressed concern over the apps. For the Air DJ app, one participant found it too simple (P6: *"The DJ game was too simple, there should have been more functions. Like a keyboard or something. Or maybe even track mixing."*). For the Air Guitar app, one participant (who is a bass guitarist) mentioned the problem of not supporting open strings (P5: *"If there were open strings, the guitar app would be much better."*). Another participant (who is a sound production engineer and musician) mentioned that generally he would prefer the magnet-based ADI if it allowed for continuous control over the magnet signal (P21: *"For me, it would be good to find a way to measure the magnet signal so that it is not only a trigger, but a continuous signal. So basically a controller."*). Despite his concerns, this same participant was able to easily compose music with the Air Guitar app, where he composed the Jingle Bells tune upon request (see attached Video).

Social Acceptability

Participants were asked about how socially acceptable interacting with the ADI-based apps using a magnet is in public places, and whether they would do it in public (e.g., metro, café). Most (18/24) stated they would (P17: *"Yeah, I wouldn't care, people can do what they want. It actually feels quite natural to play with this."*), however two of those participants mentioned that they would do this only if they had headphones on. From the six participants who stated they would not, three mentioned they would if they were with a group of friends (P19: *"If I'm alone, no. But with friends, yeah why not."*). Another participant mentioned he would engage in such interaction if the magnet form factor was more appropriate (P5: *"Yes, as long as it looks cooler than this. If it was a magnet pick, maybe yeah."*). Together, these findings provide early indicators that magnet-based ADI may become part of people's daily lives, even in public settings. However, to fully verify this would require a longitudinal test of these apps in users' daily environment.

Other Magnet-based ADI Application Areas

When participants were asked about other potential use-cases for magnet-based ADI, many (16/24) had immediate ideas of other application areas. These included gesturing in the air for text entry and drawing/painting, substituting or extending basic mobile touchscreen interactions (answering call, rejecting call) when the device is occluded (e.g., in one's pocket), rhythmic skill practice (for musical training), and especially gaming. For gaming, this included first person shooters, sports games like tennis, and even an Angry Birds© adaptation. Some mentioned the potential for multiplayer collaborative gaming, especially for games like Air GuitaRhythm (however they did express that the magnets might interfere with the other player's smartphone). Together, these suggestions provide further evidence on the potential of the magnet-based ADI paradigm for supporting user activities, even outside of the music composition and gaming domains.

Discussion

Supporting Playful Music Composition and Gaming

Despite that the music-related applications we developed under the magnet-based ADI paradigm were not targeted towards professional musicians, we still expected to see a significant difference in mean AttrakDiff2 dimension scores between the musically-trained and non-musically trained groups, especially for the Air Guitar app. While there were differences for the Air Guitar in usability (PQ: Mean musically-trained: -.4; Mean non-musically trained: .2) and perceived novelty and stimulation (HQ-S: Mean musically-trained: 0.5; Mean non-musically trained: -.1), these differences were not statistically significant. However, they do partially indicate that musically-trained users were more critical of the usability of the Air Guitar app, as well as perceived it as more novel given the creativity it affords from them.

From our AttrakDiff2 scores and SUS scores, we showed that the apps based on the magnet-based ADI paradigm were generally positively perceived, and aside from the Air Guitar app, were perceived to be usable. From our user subjective reports and observations, we showed that the magnet-based ADI paradigm can indeed support playful music composition and gaming on mobile devices, and that this mode of interaction is a fun method of musical interaction. Based on these findings, we can confidently state that the creative apps (Air DJ, Air Guitar) can be used for music composition on the go, by amateur musicians and musically-affine users alike. The Air GuitaRhythm app, already at a quite usable stage, established a novel form of musical gaming experience for mobile devices. Taken together, our findings confirm our hypothesis that the magnet-based ADI paradigm can go beyond HCI work focused on user situation impairments or improving user performance when using a given ADI interaction technique (e.g., pointing and target selection (Ashbrook et al., 2011)), but be effectively applied to support playful music composition and gaming in mobile interaction.

Design Considerations for Applied Magnet-based ADI

Based on our findings, we draw design considerations that improve the user experience of using magnet-based ADI applications, specifically in the context of music-related (gaming) applications.

1. **Designing Natural Interactions:** As revealed in the interview responses (Sections

AttrakDiff2 Responses, Overall User Acceptance of Magnet-based ADI, and *Playfulness & Professional Music Performance*), users enjoy interacting with a magnet, and they find this mode of interaction quite natural. For interaction designers, this means that making use of gestural input techniques alongside touchscreen interaction (cf., Norman, 2010) for domains such as music gaming and composition is a worthwhile design goal to support entertainment.

2. **Supporting Magnet Availability & Use:** Based on participant responses (Section *Overall User Acceptance of Magnet-based ADI*), it is a valid consideration that magnets should perhaps be readily available in stores, and come in different form factors (shape, size, color) (cf., Section *Magnet Form Factor*), especially for applications that afford a direct form mapping between the magnet and the instrument/tool (e.g., guitar pick, sword) it uses (cf., Grandhi et al., 2011). Additionally, based on some participant responses, support for carrying the magnet (key chains, phone casings) should also perhaps be readily available.

3. **Transparency in Application Calibration:** Based on user's remarks concerning magnet sensitivity (Section *Overall User Acceptance of Magnet-based ADI* and Section *Magnet Form Factor*), should have immediate access and information on calibrating the magnet sensitivity, given the shape, size and strength of the magnet with respect to the application.

4. **Effective Use of Multimodal Feedback:** Given user concerns over interaction methods with the music-related apps (Section *Interaction Methods and Styles*), the apps should be augmented with multimodal feedback where necessary (e.g., vibrotactile alongside visual feedback on digital guitar strings), so as to allow smooth simultaneous physical and touchscreen interaction. Additionally, physical form extensions to a mobile device would allow for more natural musical interactions (e.g., guitar casing).

5. **Gamification for User Engagement:** To ensure engagement with creative musical apps by non-musically trained users, game-like elements (gamification) (Deterding et al., 2011) can augment the user experience (cf., Section *Interaction Methods and Styles*).

6. **Addition of User-requested Features:** To extend these musical apps to support professional musicians, extra features need to be added (e.g., magnet as controller, open strings, DJ mixing) (cf., Section *Playfulness & Professional Music Performance*) alongside other application areas for magnet-based ADI (cf., Section *Other Magnet-based ADI Application Areas*), such as rhythmic skill practice and a wider variety of games.

7. **Requirement of Longitudinal In-the-Wild Testing:** Given that most of our participants found magnet-based ADI to be socially acceptable when used in public settings (cf., Section *Social Acceptability*), designing ADI for social settings, while still requires further longitudinal real-world testing, provides an early indicator that this form of interaction may be socially acceptable.

Study Limitations

There are three potential limitations to the present study. First, since our study was conducted in a laboratory, it had less ecological validity. However, since participants were tested in pairs (where in most cases they did not know each other beforehand) and given the presence of the two experimenters, the experimental setting closely resembled natural situations. Moreover, given that participants mostly found the magnet-based ADI to be socially acceptable (amidst present strangers) and their positive responses on the naturalness of this mode of interaction, our results can likely be generalized to outside of the laboratory usage scenarios. However, at this stage it is difficult to predict whether long-term usage of these apps would provide the same level of entertainment for the everyday user. To address this, we propose to include gamification (Deterding et al., 2011) elements to all the music apps, to ensure long-term user engagement (discussed under Section *Design Considerations for Magnet-based ADI*).

A second limitation was that two of the tested apps (Air DJ, Air Guitar) were still in an earlier stage of development, where participants explicitly mentioned that the Air DJ app could benefit from more features, and the Air Guitar app was buggy at times (either too sensitive or not sensitive resulting in double or no strokes). Indeed, while these two apps could have been improved upon further, our findings indicate that they were nevertheless useful probes into the validation and suggestion of design improvements for the magnet-based ADI paradigm. Related to this point, at this stage we have not measured the time spent by users on each app. While such a measure might provide useful insight into user engagement, this would be more useful at a stage when the apps are more fully developed, and deployed to users across smartphone game stores (e.g., Apple App Store© or Google Play Market©). With a higher sample of users, and observing playing time interaction over a longer period, this measure would be more useful.

Lastly, since the present work had dealt with only magnet-based ADI, we may not immediately generalize our findings to other ADI paradigms (especially in cases where optic techniques are used instead of magnets). In such cases, the interaction of using or not using a magnet may sufficiently differ to warrant a redesign of the tested apps. Furthermore, in other variants of the ADI paradigm, the space of interaction around the device may be more complex, for example by switching the mode of interaction depending on where around the mobile device the user interacts (e.g., front, back, or side of mobile device (cf., Baudisch & Chu, 2009). While we have not made a comparison of our magnet-based ADI for playful music composition and gaming with other ADI variants, our findings nevertheless showed that participants understood the concept behind ADI (P11: *"This kind of personal space interaction felt very natural, would it be possible to do this without the magnet?"*) and its application areas.

Future Work & Conclusions

Future work needs to address the usability (cf., Sections *AttrakDiff2 Responses* and *System Usability Scale Responses*) of the Air Guitar app and enriching all the apps with additional features (e.g., adding game elements to the creative apps, collaborative gaming). To further establish the applied use of the magnet-based ADI paradigm, other non-music related apps need to be developed and tested (e.g., rhythmic skill learning). Additionally, despite that the goal of this paper was to introduce music composition and support playfulness through the magnet-based ADI paradigm, future work should test touchscreen only input as a control comparison to validate whether supported gesture-based interaction in magnet-based ADI is preferred. Finally, how magnet-based ADI and vision sensing techniques can be synergistically combined to allow more complex and touchless 3D interactions around a mobile device for music composition and gaming needs to be further investigated.

In this paper, we presented the results of a user study to investigate whether the magnet-based ADI paradigm can be effectively used to support playful music composition and gaming on mobile devices. In line with our hypothesis and the goal of this paper, we were able to show that this paradigm does offer a playful and natural interaction method for composing music and playing music-related games, and is entertaining to users. We hope to have set the stage for further experimentation with applied use-cases across domains of the ADI paradigm in general, and magnet-based ADI in particular.

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Appendix A

#: _______

MagiMusic AttrakDiff2 Evaluation

Following are pairs of words to assist you in your evaluation of each MagiMusic app. Each pair represents extreme contrasts. The possibilities between the extremes enable you to describe the intensity of the quality you choose.

Do not spend time thinking about the word-pairs. Try to give a spontaneous response. You may feel that some pairs of terms do not adequately describe the iPhone® app. In this case, please still be sure to give an answer. Keep in mind that there is no right or wrong answer. Your personal opinion is what counts!

1: first app 2: second app 3: third app
(Mark spaces, not lines. You can change ratings you've done earlier, if you wish)

1	Human								Technical
2	Isolating								Connective
3	Pleasant								Unpleasant
4	Inventive								Conventional
5	Simple								Complicated
6	Professional								Unprofessional
7	Practical								Impractical
8	Ugly								Attractive
9	Likeable								Disagreeable
10	Cumbersome								Straightforward
11	Stylish								Tacky
12	Predictable								Unpredictable
13	Cheap								Premium

14	Alienating		Integrating
15	Brings me closer to people		Separates me from people
16	Unpresentable		Presentable
17	Rejecting		Inviting
18	Unimaginative		Creative
19	Good		Bad
20	Confusing		Clearly Structured
21	Repelling		Appealing
22	Bold		Cautious
23	Innovative		Conservative
24	Dull		Captivating
25	Undemanding		Challenging
26	Motivating		Discouraging
27	Novel		Ordinary
28	Unruly		Manageable

Appendix B

#: _____

System Usability Scale

Instructions: After playing with each MagiMusic app, please tick each box below with the number of the app, to best describe your reaction to it.

1: First app **2**: Second app **3**: Third app

		Strongly Disagree				Strongly Agree
1.	I think that I would like to use this app frequently.	☐	☐	☐	☐	☐
2.	I found this app unnecessarily complex.	☐	☐	☐	☐	☐
3.	I thought this app was easy to use.	☐	☐	☐	☐	☐
4.	I think that I would need assistance to be able to use this app.	☐	☐	☐	☐	☐
5.	I found the various features in app were well integrated.	☐	☐	☐	☐	☐
6.	I thought there was too much inconsistency in this app.	☐	☐	☐	☐	☐
7.	I would imagine that most people would learn to use this app very quickly.	☐	☐	☐	☐	☐
8.	I found this app very cumbersome/awkward to use.	☐	☐	☐	☐	☐
9.	I felt very confident using this app.	☐	☐	☐	☐	☐
10.	I needed to learn a lot of things before I could get going with this app.	☐	☐	☐	☐	☐

This questionnaire is based on the System Usability Scale (SUS), which was developed by John Brooke while working at Digital Equipment Corporation.

Appendix C

#:_____

"MagiMusic" Exit Questionnaire

Please answer each question based on your experience with the iPhone® apps. For most questions, you have to fill in a number (between 1-7; 1-very bad & 7-very good) that best represents your experience for each app.

1) What was your first impression of the app?

1	2	3	4	5	6	7
Very bad						Very good

App 1: _____________

App 2: _____________

App 3: _____________

2) Was it easy to learn?

1	2	3	4	5	6	7
Very easy						Very difficult

App 1: _____________

App 2: _____________

App 3: _____________

3) Was it comfortable to play with the app?

1	2	3	4	5	6	7
Very comfortable						Extremely uncomfortable

App 1: _____________

App 2: _____________

App 3: _____________

4) Did you enjoy making music with the app? What was good or bad?

1	2	3	4	5	6	7
Not at all						Very much so

App 1: _______________ Good/bad: ___________________________

App 2: _______________ Good/bad: ___________________________

App 3: _______________ Good/bad: ___________________________

5) I would be willing to carry a magnet with me to play with these apps.

1	2	3	4	5	6	7
Not at all						Definitely

Appendix D

1) What is your overall impression of the experiment session? *[warm up]*

2) How do you feel about interacting with the apps using a magnet? How would you use it?

3) What are your expectations about the availability of magnets when you download a MagiMusic app?

4) Preference for magnet size or shape? What for you is the perfect magnet?

5) What other apps *[typical mobile tasks]* can you think of where you can use magnets to interact with your phone?

6) Would you play with these apps in public places (e.g., bus, metro, mall, street, etc.)? Would you find it socially acceptable?