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HUMAN CENTERED DESIGN APPLIED TO PERCEPTUAL PARADIGMS

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This thesis by Jonathan Fancher is recommended for approval by the student's Thesis Committee and Department Head in the Department of Psychology and by the Assistant Provost of Graduate Education and Research.

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ABSTRACT

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This thesis gives three examples of projects that apply knowledge from areas such as human centered design, computer science, and psychology to study sensation and perception. All three of these projects were created to gather information on how humans interact with their surrounding environment and the world. For instance the first area of discovery included the way humans interact within their perceptual and personal space through an interactive table. The second project looks at exploring the neural mechanisms that affect Haptic Hallucinations by creating a device that can give the feeling of bugs crawling on or below the surface of the skin. The final study is an experiment, which looks to study tactile spatial acuity through laser cut stimuli and recording movements of exploration.

ACKNOWLEDGMENTS

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INTRODUCTION

My research thesis focuses on how humans understand and interact with their environment through the usage of technology; more specifically I discuss three different research projects related to human perception where I designed devices and tools that contributed to the understanding of basic neural mechanisms of spatial and tactile perception.

The first project is related to InGrid, an interactive grid table that allows users to interact with touch-screen tablets and slide digital content from one tablet to another. The whole concept of InGrid is related to the peripersonal and extrapersonal spaces and the acquisition of knowledge. The project started when I joined the psychology master program with a desire to extend my design knowledge to psychological aspects. The Grid Table Series, a set of tables designed during my senior undergraduate project, inspired InGrid. The motivation behind InGrid was not only to add digital technology to a physical table, but also to understand basic concepts related to embodied cognition. My first chapter is an overview of the design based on evidences related to the usage of tables and tablets in a historical timeline, followed by concepts related to the perceptual and embodied spaces, and finally the possible extension to what is known in human-computer interaction (HCI) as blended interaction; i.e. blending the physical and digital world within the same interaction.

The second project is related to the design of a haptic sleeve. In order to study the phenomenon of haptic hallucinations that consists of the sensations of insects crawling on and/or underneath the skin. Although this was not my main project for my thesis, I was eager to participate on this project, as it extended not only my design skills to the usage of electronics, but also my knowledge related to a phenomenon that is not completely understood. The Haptic Hallucination Sleeve was presented at the WorldHaptics Conference in Daejeon, Korea, along with 79 other demonstrations. WorldHaptics brings together experts and well-known researchers in the field of haptic research, and the best demo award is presented during the closing ceremony, the demonstration allowed attendees to try on the sleeve, judge the realistic qualities of the tactile sensations, and give feed back on their perceptual experience. This phase was crucial, as about 300 attendees tried the sleeve on, and substantial positive feedback was received. Most importantly, the sleeve was selected among the finalists (top 3) and nominated for the best demo award by the award committee of the conference. Erin Smith, a master's student within the same laboratory, is currently using the sleeve to understand the neural mechanism of haptic hallucinations using EEG recordings.

The third, and last project is related to perceptual tactile acuity that combines a tactile spatial stimulus (tactile grating) with a localization/counting task. This project required the use of a 2D laser engraver to create the tactile stimuli used in the experiment where participants had to locate the position of an "intruder" stimulus among a grating stimulus, i.e. a series of equidistant embosses and grooves in one specific orientation. The intruder was an emboss that had a different thickness. Participants had to explore the pattern with their index fingertip of their dominant hand and determine the position of the intruder. During the exploration, participants were wearing a cuff, designed for the purpose of this experiment that allowed the recording of their movements on a Wacom Cintiq 12WX 12-

Inch Tablet. The results showed that the thickness affected participants' performances when exploring the grating stimuli. These findings contribute to our understanding of human tactile perception.

CHAPTER ONE: INGRID.

1. EVOLUTION OF TABLE DESIGN

Tables and tablets evolved from basic artifacts to their current usage in contemporary society. Merriam Webster defines table as “a piece of furniture with a flat surface that is designed to be used for a particular purpose” (“Merriam Webster Dictionary,” 2013). According to this definition, a desk can be called a table because it has a “flat surface” and a “purpose”. Other examples of tables include end tables, coffee tables, kitchen tables, credenzas, and conference tables.

When tables are small, the word tablet can be used to describe them. The word comes from the French word “tablette” that is defined by Larousse, a French dictionary, as a small table or a horizontal board that receives objects and/or can be a support for writing (“Larousse,” 2013). Tablet can also refer to a writing surface, such as clay tablets or touch-screen tablets.

The first evidence of using a flat surface was found at the prehistoric stone houses in Skara Brae (circa 3500-2600 B.C.) Figure 1), on the Orkney Islands, North of Scotland. The structures found in this area are made out of stone. According to Postell, “…what remains today are built-in seats and platform sleeping spaces…” (Postell, 2007). There is no clear evidence of “table” usage. However, it is also possible that these flat surfaces have been used to support objects. The first solid documentation of a table usage comes from the early Egyptians, where Baker reported: “Stone tables were apparently in General use in the Dynastic Period” (Baker, 1966). These stone tables were less likely mobile or transportable because of the nature of the material. Sir William Flinders Petrie and later Professor W. B. Emery excavated tombs from the First Dynasty and discovered the remains of the oldest known wooden furniture, dating from about 3100 B.C. among them a table made out of a single piece of wood. It is plausible to speculate that since wood weighs less than stone, this piece of furniture was more likely moveable (Baker, 1966). The advancement in woodworking technology compared to the use of stone, not only marks the birth of the first furniture, but also contributes to the general path of human creativity and the need to make objects mobile, lighter, and easy to manufacture. "By the beginning of the first Dynasty, the basic principles of woodworking were already well established, and the mortise and tenon joint – one of the most practical inventions of the ancient woodworkers – was in common use" (Baker, 1966).

FIGURE 1. SETTLEMENT AT SKARA BRAE, ORKNEY (FROM HTTP://BRITISH-HISTORY.NET/ANCIENT-BRITAIN/THE-CELTS-BEFORE-ROME/).

Interestingly, the Egyptians were not using the table for current everyday usage, but was mainly used to support objects. It seems that the Greeks and Romans were the first to use tables for eating and gathering people around. Evidence showed that they were also used as an area for writing and working (Hayward, 1979). Tables became a platform for knowledge, a place to display artifacts or objects, or an eating area while conversing with other people.

While Greeks and Romans changed the utility of tables, the main developments were the results of the industrial revolution that witnessed the creativity of artists and companies such as Gebrüder Thonet of Boppard am Rhine from Germany. Their creations were modular and most importantly assembled or disassembled into pieces. This was the first documented case of a company producing knock-down pieces that provided a cost-effective means to distribute furniture to a global clientele" (Postell, 2007). This aspect was important for two reasons: i) mobility and modularity and ii) opening to the global market, as before Thonet furniture was not mass-produced. This transportability of furniture opened the market to a new generation of furniture that was modular, light, and moveable. The bent wood allowed for less weight compared to the bulky mortise and tenon joints used on ancient wooden tables. The new design technique allowed the nesting of wood pieces. This endorsed mobility and modularity and opened the possibilities for designers to create new sets of tables that could be adapted to the users' needs and/or environment.

The Machine Age (1910-1945) was the next large impact on tables and furniture; this was an era of manufacturing in mass quantities that witnessed the rise of Modernism, which is a philosophical movement that focuses on rectilinear and geometric shapes or structures that were devoid of any ornamentation to expose physical aspects of materials such as steel, wood, aluminum, glass, and concrete. During this era, the design of tables was kept to clean "bare essentials" to reduce the costs. Decorative ornate styles like Baroque style furniture faded away because they took too long to manufacture and therefore were more costly. The machine age witnessed the appearance of new materials such as plastic, plywood, or steel and are still used today for furniture design (Postell, 2007). For instance, Figure 2 shows *Laccio Coffee Table,* a piece of 20th-century furniture by Marcel Breuer's. Similar to Thonet's Bentwood Furniture, Breuer' table is modular, light, and can be broken down into several pieces. It is made out of bent tubular steel, particleboard, and laminates that made a high ratio of durability for weight. The simplistic designs during the Machine Age are still a preferable look that today designers are seeking.

FIGURE 2. LACCIO COFFEE TABLE (FROM HTTP://WWW.KNOLL.COM/PRODUCT/LACCIO-COFFEE-TABLE)

Ikea applies this design principal to several of its creations, such as their Lack Series. This series consists of minimalistic end tables, shelves, and coffee tables with thicknesses that give a heavy weight appearance. This illusion is caused by a hollow construction technique used by Ikea that stacks honeycomb shaped cardboard between two layers of wood or laminate (“IKEA,” 2013). These tables differ in the structure because of the honeycomb placed between two layers of thin wood. This shows that technology evolves and adapts to the need of the individuals, including designers, engineers, and manufacturers and allowing them to create furniture with a certain look that is affordable.

2. FROM CLAY TO TOUCH-SCREEN TABLETS

Merriam Webster defines tablet as “a flat slab or plaque suited for or bearing an inscription” (“Merriam Webster Dictionary,” 2013). This shows a common proof of a concept between clay tablets and what is commonly known as touch-screen tablets. A good example of what a clay tablet was used for was the Sumerian cuneiform, a wedge-shaped writing system, that would be impressed by a stylus into soft clay tablets, which were later hardened (“Encyclopedia Britannica,” 2013). The similarity of using a tool such as stylus to inscribe knowledge on a flat surface is interesting, because people today still use styluses, but on a digital medium. The technological shift extended the possibilities of interactions with the device in a such a manner that the device itself became mobile, but also with clay tablets. Indeed, the first documented miniature books (could be similar to Kindle) were 2 inches in height cuneiform tablets (see Figure 3). The word tablet is also used to refer to a category of touch-screen displays such as Google Android or Apple iPads. This is probably because of the similarities with clay tablets where the purpose is to inscribe knowledge content using a small size surface. Of course, touch-screen tablets extend the acquisition of knowledge and this could be taken a step further because the content itself is not physical anymore and becomes virtual for the user. Although the debate is quite interesting, it is out of the scope of this thesis. However, it is important to point out that it creates an interesting philosophical discussion related to the support of knowledge and how our relationship to the materiality and immateriality of how objects change our perception and interaction with the world.

FIGURE 3. BABYLON CLAY TABLETS (FROM

HTTP://COMMONS.WIKIMEDIA.ORG/WIKI/FILE:BABYLON_CLAY_TABLETS.JPG)

3. BLENDING TABLE AND TOUCH-SCREEN CONCEPTS

Touch-screen technology has opened the door for more creativity and also extended to tables by interactive technology known as touch-screen tabletops and multitouch displays in a form of a table. Multitouch tabletops and surfaces are not a new concept in Human-Computer Interaction (HCI), as several interaction techniques were already developed such as vision based detection (Muller-Tomfelde, 2010), tiled LCD displays (Krumbholz, Leigh, Johnson, Renambot, & Kooima, 2005), fingerprints (Holz & Baudisch, 2010), or finger orientation (Zhang et al., 2012). They all share two characteristics in common: i) they were designed for collaborative interaction, and ii) their cost limits their usage to work or research environments, although some research was intended to develop tabletops for living spaces (Seifried et al., 2009). Recent research development focuses on the blended interaction aspect of surfaces, i.e. interaction in both physical and virtual objects. For instance, IdeaVis and AffinityTable both used paper based interaction techniques and offer the possibility of personal space (Geyer, Budzinski, & Reiterer, 2012), (Geyer, Pfeil, Budzinski, Höchtl, & Reiterer, 2011). CRISTAL (see Figure 4) and NiCE (see Figure 5) also allows interaction between tangible and intangible interfaces. For instance, CRISTAL allows controlling electronic appliances in a room through a touch screen coffee table. The whole concept has been designed to bring this technology to household setting (Seifried et al., 2009). In a work setting, the "future meeting room", not only blends the interaction between different types of displays (small and large screens) but can keep the personal space private if desired during the interaction with touch-screen tablets. Finally, Sprindler et al. extended the interaction space to the 3D space above the table by using small screen displays

(Spindler, Martsch, & Dachselt, 2012). All these concepts deal with the embodied perceptual and personal spaces detailed below.

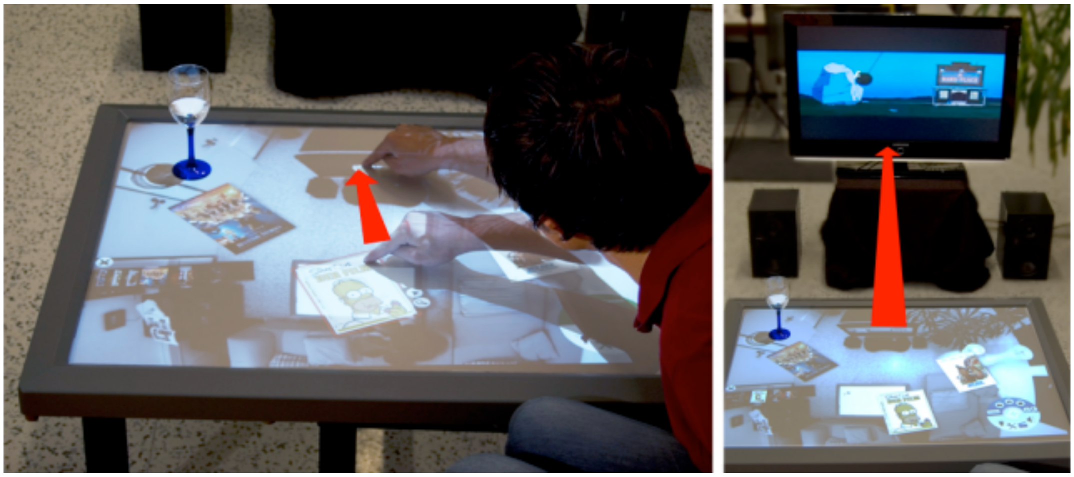

FIGURE 4. CRISTAL (FROM HTTP://MI-LAB.ORG/PROJECTS/CRISTAL/)

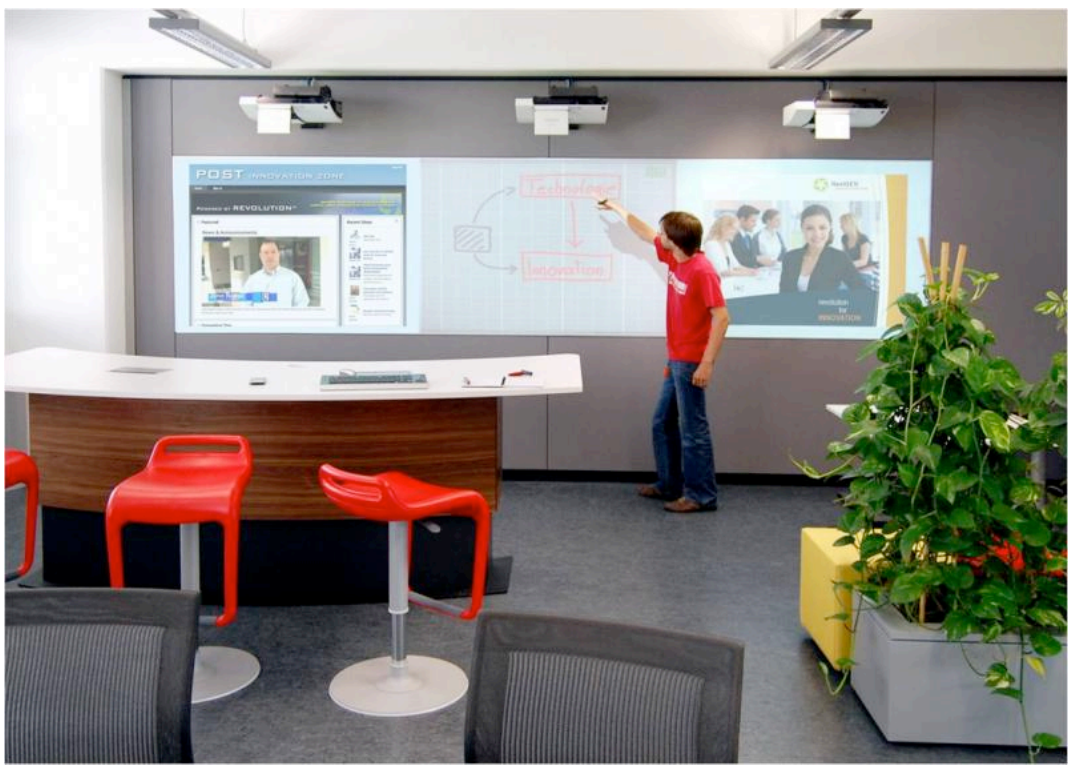

FIGURE 5. NICE DISCUSSION ROOM (FROM HTTP://MI-LAB.ORG/PROJECTS/NICE-DISCUSSION-ROOM/)

4. INGRID: INTERACTIVE GRID TABLE

One of the main drawbacks of interactive tabletops is they lose their usage as a table. Indeed, a tabletop is used only as a multi-touch surface and is rarely used as gathering or an eating surface. The functionality of a table changes to focus more on the interactive aspect with the virtual content. In fact, the way technology changes our relationship to our body and space changes not only our acquisition of knowledge but also our interaction with cognitive tools. This aspect of embodied cognition raises interesting questions related to the way tools or technology can be perceived or felt as being an extension of the body. On one hand, tabletops are a very good example of embodiment; they extend the user's actions but they also modify their perceptual and personal spaces. On the other hand, they are a good paradigm for natural User Interface (NUI) and tangible user interfaces (TUI). I will discuss in the following sections the concept of embodied personal and perceptual spaces while using interactive tabletops that have been the starting point of designing InGrid; an interactive grid table that blends the virtual and physical aspect without losing the table functionality aspect that is always missing with the multi-touch tabletops.

4.1. EMBODIED PERCEPTUAL SPACE

When interacting with virtual content, the perceptual space can be divided into physical and virtual spaces (Ziat, Gapenne, Lenay, & Stewart, 2005). Both spaces can be divided in turn into embodied and disembodied spaces. The disembodied space is any tangible or intangible space that does not necessary extend the body physically or virtually, while the embodied space is the space where knowledge acquisition and human experience take place. It is the space of perceptual experience and consciousness (Low, 2003), the space where a user interacts not only with tangible but also intangible (virtual) objects. Indeed, embodied cognition encompasses body and mind. Actions in the world affect our knowledge acquisition and human experience and, in turn, knowledge, experience and consciousness affect the way we act in the world.

Collaborative tabletops are an interesting concept to study the embodied space; Not only do they extend the users' sensorimotor capacities but also their cognitive abilities. While interacting with collaborative tabletops or touch-screen tablets, the tangible and/or intangible object can be felt as "temporarily" extending the body's sensorimotor space. As explained by Lenay (Lenay, 2012), the temporary aspect of "feeling ownership" is that the tool extension ceases when the user is not anymore in contact with the object. When the user is not touching anymore, the touch-screen the embodiment extension stops.

Another important aspect of tabletops is that the embodied perceptual space can be intangible. If the user were observing other agents interacting with the virtual content on the multi-touch tabletop, and thus being cognitively engaged in the task without necessarily touching the screen, the embodiment extension would remain at a cognitive level even if it terminated at the sensorimotor level. Costantini et al. demonstrated that observing someone else's actions with a tool may extend the representation of peripersonal space and shape the way we coordinate and integrate our own actions with those of others (Costantini, Ambrosini, Sinigaglia, & Gallese, 2011). In summary, the embodied space in collaborative environments depends not only on the user's interaction in a specific spatial configuration, which defines their peripersonal space, but also on the way other users are interacting with the same display, the same space, or the same content, which can represent, at some degree, their extrapersonal space.

FIGURE 6. THE PERIPERSONAL SPACE WHEN WORKING ALONE

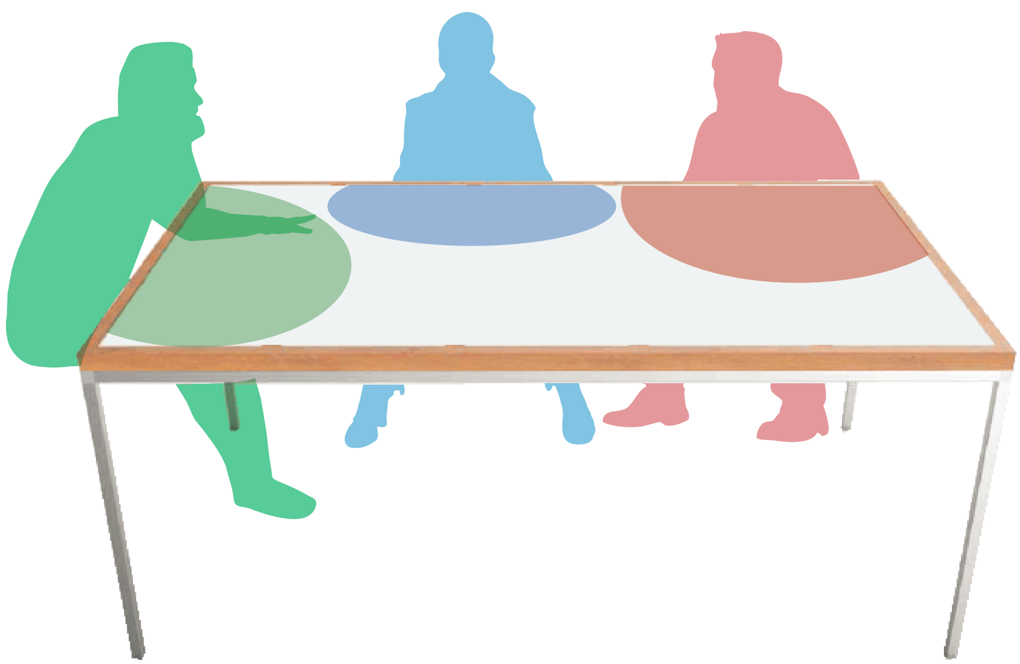

FIGURE 7. THE PERIPERSONAL SPACE WHEN WORKING IN A SHARED SPACE

4.2. Embodied personal space

From a neuropsychological framework, the embodied personal space is mainly described in terms of peripersonal and extrapersonal spaces[1]. For instance, if a person is working by themselves on a table, they can extend their peripersonal space by surrounding this space by several objects such as books, a laptop, or a cellphone (Figure 6). Their peripersonal space on the same table would shrink if another person was sitting nearby or several were working at the table (Figure 7). The sensorimotor invariants in both situations are different because both sensory inputs and space of actions have been modified. Neurological evidences in Monkeys showed that the same neurons that fire for the nearby peripersonal space start firing near the far end of a rake, when the monkey had become skilled in using the tool that extended the reachable space (Ishibashi, Hihara, & Iriki, 2000). This suggests that while interacting with flat surfaces or tabletops, the peripersonal space can be modified depending on the tools used to extend the body but also depending whether the space is inside or outside the person's workspace. This was suggested by another study that showed that neurons are encoded differently whether objects in the peripersonal workspace prevented the monkeys from reaching the area close to the body (Caggiano, Fogassi, Rizzolatti, Thier, & Casile, 2009).

Although, according to De Preester's classification (De Preester, 2010), an interactive tabletop would be rather a technology incorporated to the body rather than an extended

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[1] A third space, that is not discussed here, represents the percutaneous space that

one. De Preester argues that is not a matter of permanence or separability but rather a difference in the feeling of body ownership. Indeed, they distinguished between embodiment extension and embodiment incorporation depending on whether the tool changes body ownership. Although this distinction raises interesting questions related to embodied cognition, we agree with Lenay, that De Preester's classification needs some clarification. For instance, De Preester claims that perceptual prostheses such as microscopes or telescopes do not change the nature of our perceptual experience and in this sense are more incorporated than extended to the body. However, when observing a planet with a telescope or a microorganism with a microscope, you can see details that the human eye cannot experience. Zooming, in this case, is an "extended" capacity to the human eye limitation. The sensation at the end of the magnifying tool and the action at focus knob both define the space of sensorimotor invariants (Ziat, Gapenne, Stewart, & Lenay, 2006), (Ziat, 2007), (Ziat, Gapenne, Lenay, & Stewart, 2007). If one removed one's eye from the magnifying tool, a drastic change occurs in the sensorimotor contingencies (O'Regan & Noë, 2001) and thus in the perceptual experience (i.e. from seeing a living micro-organism to a tiny spot on a microscope slide). We believe that the embodied experience depends on the permanence (temporary or not) of the object in the embodied space and the changes that it can bring within sensorimotor contingencies. This can be obtained by having a completely immerged user in the space of interaction. By analogy, interactive tabletops can be experienced as an extension of the body because not only the users are immerged in the sensorimotor space but also through the space of shared and private knowledge. The sensorimotor contingencies of interactive tabletops represent the space of actions and sensations that can be defined by extracting the sensorimotor invariants in both peripersonal and extrapersonal spaces.

4.3. INGRID: INTERACTIVE GRID TABLE

4.3.1. THE GRID TABLE SERIES

The motivation behind the concept of the Grid table was to explore whether it was possible to have a more fluid utilization of surfaces in a domestic household. When interacting with flat surfaces and mainly tables, the users tend to utilize surfaces for:

- Unintended purposes: It is common to use tables for functions that were not initially intended for. For instance, a kitchen table can be used as a desk, a coffee table to rest one's feet, a dinner table to do homework or read the mail, and so on.

- Putting/Taking objects on/off for different functions: Tables can be used as support for food, decorative objects, or personal objects that bring memory back.

- Adapting flat surfaces to their needs: tables can be used to organize and/or store objects in both peripersonal and extrapersonal spaces.

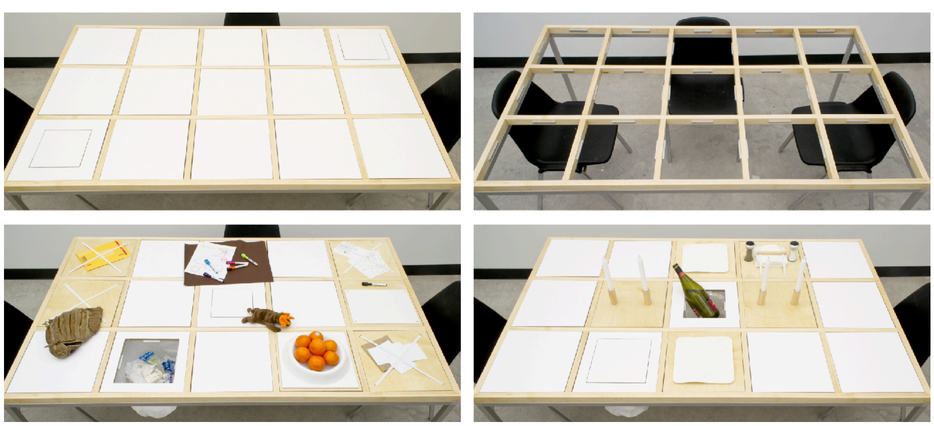

FIGURE 8. DYNAMIC TABLE LAYOUTS

4.3.2. TABLE TILE

The tiles' size was designed to stay in the range of the peripersonal space (space of reach). However, all the tiles together form the shared space that consists of the extrapersonal space (space out of reach). The peripersonal space, and thus the extrapersonal space, depends on the number of persons around the table, the reachable space, and the number of tiles that can be moved around (Figure 6 and Figure 7). Each time a tile is flipped (Figure 9), the peripersonal space offers a new perceptual experience and a variety of affordances. For instance, the same table (space) can be used as a working area, gathering area or eating area (Figure 8) depending on the tile that is in the perimeter of the peripersonal space. A cutting board tile would afford the possibility of cutting, while a writing tile would afford the action of using a pencil to either write or draw. Finally, it could afford interacting with virtual content while using a "tablet tile" designed for touch- screens (Figure 10).

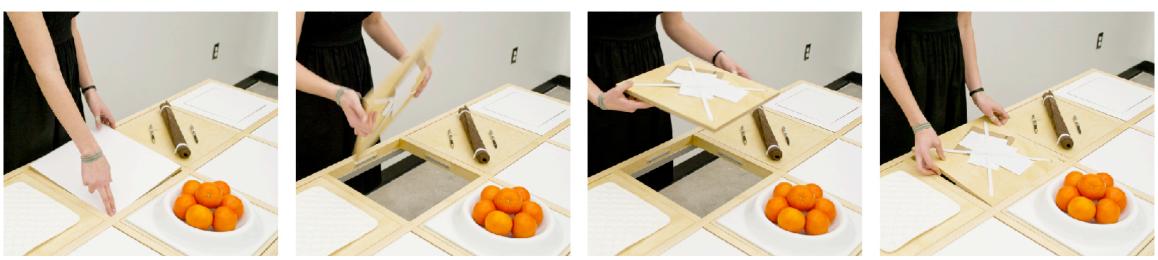

FIGURE 9. HOW TO FLIP A TILE

4.3.3. INGRID

A user can decide to share the content with other users or keep it private and/or interact with the tiles that are in her peripersonal space. Sliding the virtual content from a tablet A toward the direction of a tablet B is similar to sliding an object such as a book on the table that does not require implicit thinking, effects sharing the information. Indeed, implicit memory happens without conscious awareness; the same way, one walks down the stairs or the street. The movement would become choppy, if one started thinking about its execution. Thus, InGrid allows a similar interaction by detecting the position of the tablets and the direction in which the user is dragging the virtual file. The user does not think consciously about natural gestures or motor actions she reproduces or performs.

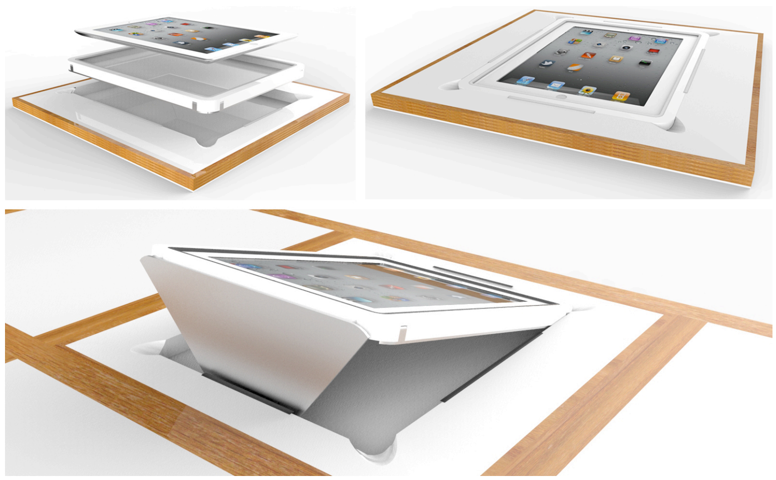

FIGURE 10. TABLET TILE

4.3.4. BLENDING TANGIBLE AND INTANGIBLE

InGrid is also a blended interactive table in a sense that the information about the location of the tiles can be displayed on the tablets. For instance, if all the tiles are flipped on their laminate side, the location of one specific functional tile could be tedious, requiring the user to either look under the table or flip each tile one by one until finding the tile of interest (for instance the hotpot). The blended aspect allows to bring tangible and intangible embodied space together (Ziat et al., 2005). In terms of perceptual space, the embodied space is extended when the user is touching the screen and this extension ceases when she stops touching the screen. The embodied knowledge is extended as far as the user is bodily engaged in the space of interaction (iPad and tile interaction).

4.3.5. COLOR SENSORS

We originally tried pressure and tilt sensors that detected the position of each tile and whether the tile was tilted or at a flat position. However this solution was constraining due to the wiring that limited the flipping interaction. We finally opted for color sensors that can distinguish up to 255 RGB colors. We used only 15 colors; each color being associated to one functional tile. The color sensors send the information to an Arduino and an Ethernet Raspberry Pi [16] that in turn, sends the information to the iPad's application that displays the grid and the position of each tile (Figure 5). The color sensors were also used to detect the flat vs. angle position of the tiles.

5. CONCLUSION

The combination of InGrid and The Grid Table Series creates a lot of possibilities for creating more concepts. For example, they could be adapted to children to enhance the acquisition of knowledge and creativity or could create a variety of screen combination such as mixing small and large screens.

CHAPTER 2: HAPTIC HALLUCINATION SLEEVE.

1. HAPTIC HALLUCINATIONS

Haptic or tactile hallucinations that concern primarily the sense of touch are defined as “a bodily sensation seemingly evoked by a stimulus from outside the body which occurs in the absence of an appropriate source in the extracorporeal environment “(Berrios, 1982; Blom & Sommer, 2012; Prince, 2011). More specifically, we will focus on the phenomenon of formication (also called Magnan’s Sign or “cocaine bugs (SIEGEL, 1978)”) that is described as the sensation of bugs crawling on or beneath the skin’s surface, when they are not actually present in an individual’s environment. It is important to point out that the sufferer feels an actual physical sensation of the bug. A condition different from delusional parasitoris (Ekbom's Syndrome) where patients present the false belief of the presence of insects on or inside their body without necessarily experiencing the sensation of an insect (Fellner, 2012). Nevertheless, haptic hallucinations might trigger the delusory parasitoris condition. The etiology, the type of hallucination, and the limited research can make it hard to separate tactile hallucinations from Ekbom’s Syndrome. Although Leon et al noted that classifying the symptoms as a delusion or a hallucination could affect not only the diagnostic, but also could offer to neuroimaging research a better understanding of the brain area involved in the process (de Leon, Antelo, & Simpson, 1992). Indeed, as opposed to delusions, hallucinations may be related to the sensory areas in the brain and could be studied using fMRI, optical imaging, and/or EEG techniques. More recently, researchers at Mayo clinic (Hylwa SA, Bury JE, Davis MP, Pittelkow M, & Bostwick J, 2011) showed that biopsies, taken on 108 patients, were inconclusive concerning a dermatitis or a possible skin infection, suggesting that tactile sensations could trigger the delusional condition, which corroborates Leon et al.'s classification.

2. IMPORTANCE OF UNDERSTANDING HAPTIC HALLUCINATIONS

Very little is known about haptic hallucinations when compared to visual or auditory hallucinations. Haptic hallucinations usually affect patients with schizophrenia, Parkinson's disease, drug addiction, alcohol withdrawals, Ekbom's Syndrome, or people suffering from depression. For drug abusers, 30% of those suffering from delusory parasitoris have scratching marks. Almost half of them (13%) reported haptic hallucinations (Siegel, 1982). These symptoms are not limited to cocaine abusers. Several sufferers of haptic hallucinations often have associated dermatological problems or can develop them due to the intense scratching (Siegel, 1982). These case studies point out that although haptic hallucinations are a psychological phenomenon, they can have severe physical consequences for the individual as well. Shedding light on the cortical activation for induced haptic hallucinations could offer a better understanding of this phenomenon and therefore suggest a better treatment. To study this phenomenon, we designed a sleeve that produces sensations similar to crawling bugs that could potentially activate specific neural mechanisms that could share similar pathways with haptic hallucinations.

3. DESIGN OF THE HAPTIC HALLUCINATION SLEEVE

The first phase of this research was to build a sleeve that produces two types of sensations: 1) sensation of insects crawling on the skin, and 2) sensation of insects crawling beneath the skin. In order to give the sensation of a crawling bug, a motor dragged tinny fibers connected at the end of a cable. The fiber, unseen by the participant but in contact with the skin, moves at a specific speed that gives the sensation of crawling ants. Creating sensations beneath the skin use a vibrating actuator also pulled by a cable controlled by a motor. The vibrations and their displacement along the forearm generate sensations of something moving under the skin. The haptic hallucination sleeve was presented in April 2013 at the Worldhaptics conference in Daejeon, Korea, along with 79 other demonstrations. Worldhaptics brought together experts and well-known researchers in the field, and the best demo award was presented during the closing ceremony. The demonstration allowed attendees to try on the sleeve, and judge the realistic quality of the tactile sensations, and give feedback on their perceptual experience. This phase was crucial, as about 300 attendees tried the sleeve on, and substantial positive feedback was received. Most importantly, the sleeve was selected among the finalists (top 3) and nominated for best demo award by the award committee of the conference.

FIGURE 11. HAPTIC HALLUCINATION SLEEVE

The Sleeve consists of two parts: 1) the portion that is worn on the arm and 2) the housing for mechanical and electrical components. The sleeve portion was 3D printed out of ABS plastic and was strapped to the arm using cotton and Velcro surfaces. The ABS part has a track running through its center to allow the stimulus (either fibers or motors) to be pushed or pulled through using a bike brake cable. When worn, the opening in the track allows the stimulus to be in contact with the skin. The motion of the stimulus, along with the pressure against the skin, makes the fibers gently brush the skin creating a sensations similar to static electricity, which has been used to describe little creatures crawling on the skin in people suffering from delusory parasitosis (Hinkle, 2000).

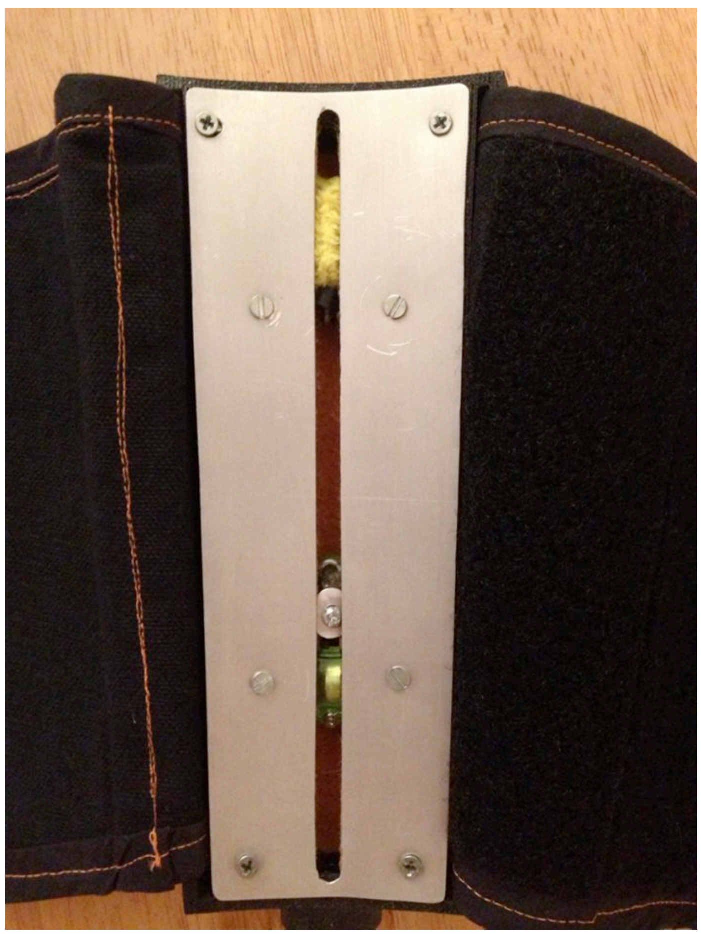

FIGURE 12. THE TWO STIMULI INSIDE THE SLEEVE

The housing part, entirely 3D printed, contains an Uno Arduino board that control the speed of a servos motor that pull the cable at a specific speed. As mentioned previously, one end of the cable is connected to the servos motor, while the other end contains the stimulus part that is in contact with the skin.

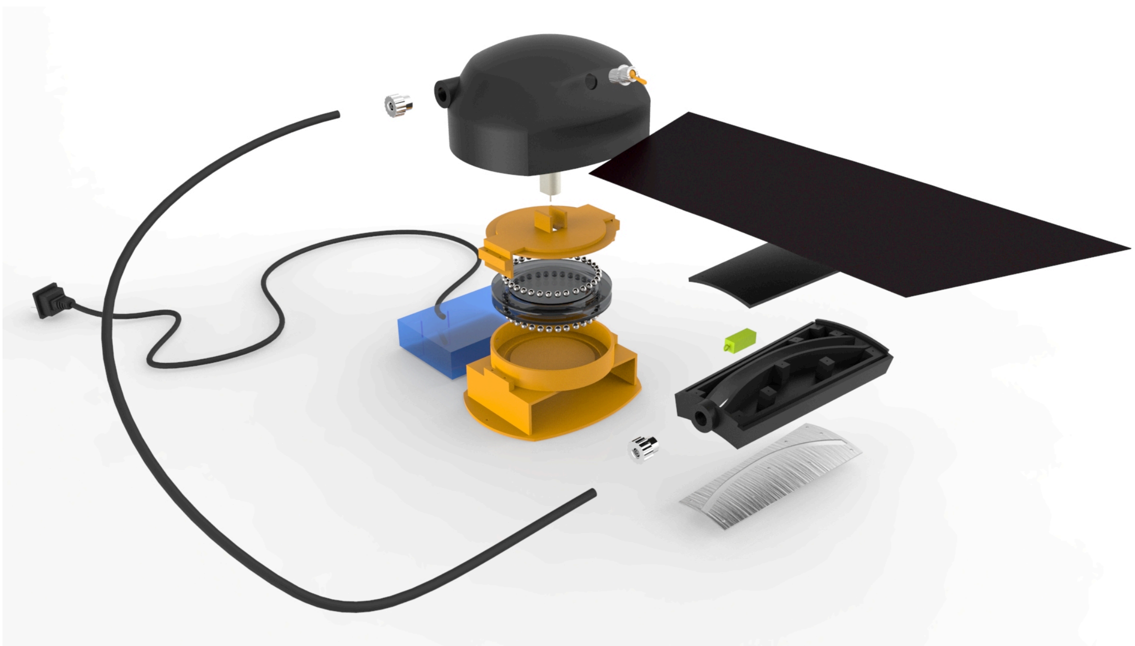

FIGURE 13. EXPLODED VIEW OF THE SLEEVE

4. FUTURE RESEARCH PLANS

The sleeve is currently being used by Erin Smith, a master student, to investigate the neural basis of haptic hallucinations. It is important to point out that the sensations created by the sleeve do not trigger the actual haptic hallucinations. However, it induced sensations similar to haptic hallucinations that are realistic enough to deceive the brain and could potentially activate the same areas activated by “real” haptic hallucinations.

CHAPTER 3: TACTILE SPATIAL SEGREGATION.

1. MEASURING SPATIAL TACTILE ACUITY

For a long time two-point threshold was the only available method to measure tactile spatial resolution. As pointed out by Craig and Johnson, that this technique is not very accurate because humans are able distinguish lower thresholds using an alternative technique known as grating orientation (Craig & Johnson, 2000). In another study Craig found the threshold of the grating orientation task to be a little as 1.16mm (Craig, 1999).

Grating orientation consists of presenting a series of grooves and ridges with a similar thickness. For instance, if the space of the groove is one millimeter thick, the ridge will also be one millimeter thick. To measure spatial acuity, the grating is presented at different orientation angles on the fingertip (Figure 14) and participants are asked to detect the direction of the grating as it becomes thinner and thinner. The threshold value is determined by the impossibility to determine the orientation of the gratings.

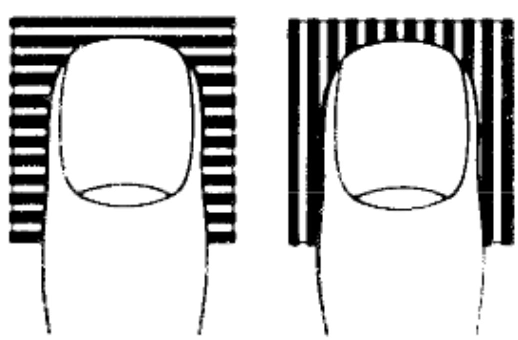

FIGURE 14. TACTILE GRATINGS ORIENTATIONS (FROM HTTP://NEUROBIOGRAPHY.INFO/TEACHING.PHP?MODE=VIEW&LECTUREID=8&SLIDE=8)

2. STATIC SPATIAL TACTILE ACUITY

As mentioned previously, the threshold is the point where participants cannot detect the direction of the grating. This measurement is often static, where the stimulus is pressed against the skin (in our case, we used the fingertip) without any movement from the participant (Goldreich & Kanics, 2006). There is no exploration of the tactile stimulus. Although, it might seem an easy task to perform, several issues require attention before measuring spatial tactile acuity such as applying a consistent pressure and ensuring that the stimulus always stimulates the same spot on the skin. Goldreich et al. suggested an innovative solution to resolve these problems; called Tactile Automated Passive-finger Stimulator (TAPS) (Goldreich, Wong, Peters, & Kanics, 2009). Figure 15 shows a drawing of the device and arrows that illustrate the different movements that it makes. A finger would be held in one place, which would usually be on a table with a hole drilled in it, allowing the each stimulus to rise towards the fingertip as they rotated around the carousel in the programed order.

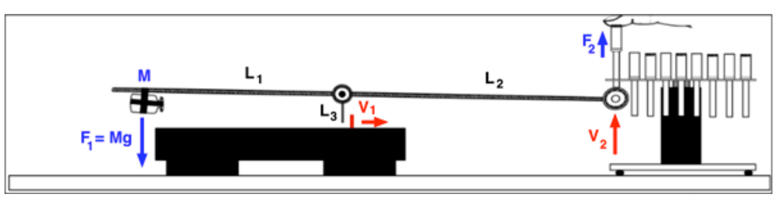

FIGURE 15. A TACTILE AUTOMATED PASSIVE-FINGER STIMULATOR (TAPS)

3. ACTIVE TACTILE SPATIAL ACUITY

Another aspect that could affect tactile spatial acuity is active exploration. Similarly, the presented stimulus is grating with grooves and ridges. However, conversely to the passive condition, participants actively explore the stimulus with their fingertips. In a 1983 study, participants were asked to move their finger side to side horizontally to discriminate between three separate stimuli. The authors changed the "spatial period" and kept the groove and ridge width ratio constant at nine. The participants' task was to identify the standard stimulus ad mists two comparison stimuli. The two standard gratings had a spatial period of 770 μm and 1002 μm, while the comparison gratings ranged from 625 μm and 1229 μm. The results showed that participants were able to discriminate a 5% difference of frequency of grooves and ridges between of two separate stimuli (Morley, Goodwin, & Darian-Smith, 1983). However, the amplitude of grooves ridges was unspecified in Morley et al.'s study and was only described briefly as a "spiky surface". In another study, Nefs et al. explored the effect of amplitude during tactile active discrimination of sinusoidal gratings. Depending on the amplitude, the acuity thresholds were larger than Morley et al. (1983), as participants were able to identify a 6.4% difference between gratings. They also found that participants were able to detect differences as little as 2μm in amplitude (Nefs, Kappers, & Koenderink, 2001).

In the study for this thesis, we asked the participants to identify whether all grooves and ridges of a grating had similar width, and if they detected an intruder ridge (different width), if one was identified, would they be able to identify its location. More specifically, we assessed participants' ability to identify an intruder ridge within a grating of 10 ridges and 9 grooves. The purpose of this study was to identify the threshold of spatial active exploration during lateral movement. The participants were asked to detect the absence or presence of the intruder, and when present, name its position.

4. METHODS

4.1. PARTICIPANTS

Fifteen participants (7 males and 8 females, between 20 and 30 year old, mean age: 20.46, SD: 2.23) participated in the experiment. They were all undergraduate and graduate students from Northern Michigan University. They all received compensation for their participation. There were 13 right-handed participants and 2 left handed participants and none of them had any irregularities that would cause issues with their tactile perception. All participants gave their informed consent before their participation to the study that was approved by the Institutional Review Board at Northern Michigan University.

4.2. STIMULUS

Sixteen different patterns were used for this experiment along with a control stimulus (example shown in Figure 17). Each stimulus was made up of a set of ten raised lines that there were evenly spaced grooves. The stimuli were created by laying out the pattern in Adobe Illustrator and rasterizing them into acrylic with an Epilog laser engraver. The acrylic lines were rasterized into a sheet of acrylic that was 0.22 inches thick, with a depth of burn of less than .01mm (our digital calipers were o. After the pattern had been rasterized, the laser printer then cut each pattern into thirty by thirty-three millimeter rectangles. Except for the control set, where all grooves and ridges had equal thickness, each set of the 16 (Figure 1) stimuli consisted of nine precise rigidities that were 200mm long by 1mm thickness and one intruder rigid that differ in its thickness. Intruders were placed at four possible positions (Pos3: 3rd, Pos4: 4th, Pos5: 5th, and Pos6: 6th) and four thicknesses (Thi2: 2mm, Thi3: 3mm, Thi4: 4mm, and Thi5: 5mm). In total there were four possible thicknesses for each of the four positions.

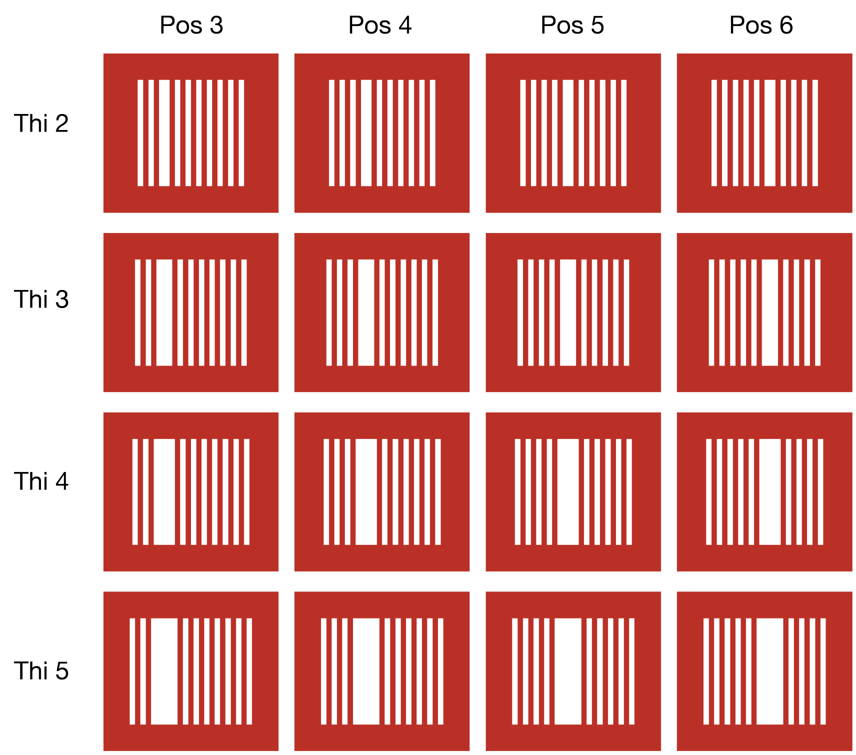

FIGURE 16. POSSIBLE INTRUDER POSITIONS AND THICKNESSES

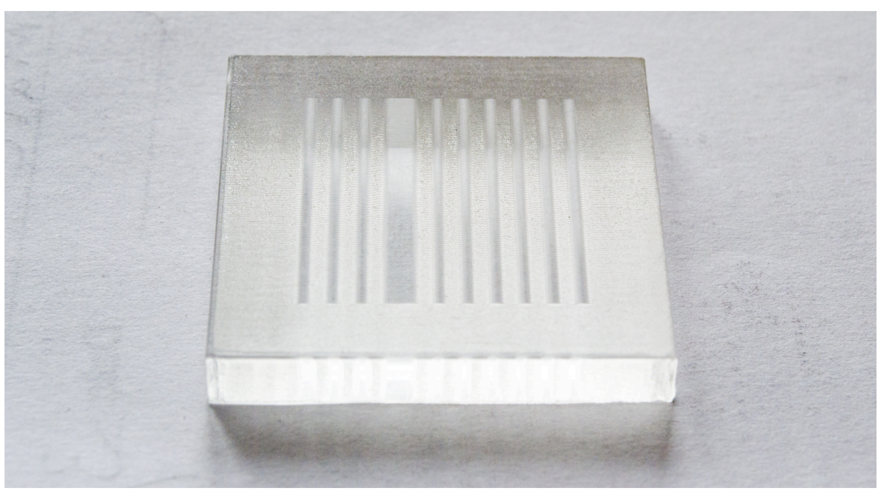

FIGURE 17. TACTILE STIMULUS TILE

4.3. APPARATUS

As shown in Figure 18, the system that held the tiles in place was a 125 mm square piece of acrylic that had a square hole in it the size of the stimulus tiles. This part was riveted to a sheet of acrylic that was the same size and was adhered to the experimental table using Velcro.

A Wacom Cintiq 12WX 12-Inch Pen Display was being used to record participants' movement. It was possible by strapping a cuff to participants'. As shown on Figure 19, the cuff had a part that ran perpendicular to the participants' arm and had the tablet's stylus attached at the end of it. When participants explored the tactile stimuli, they moved the stylus attached the cuff on the tablet and therefore created drawing trajectories that were recorded using SketchBook Express, a sketching and painting software, and QuickTime that would be used for farther analysis.

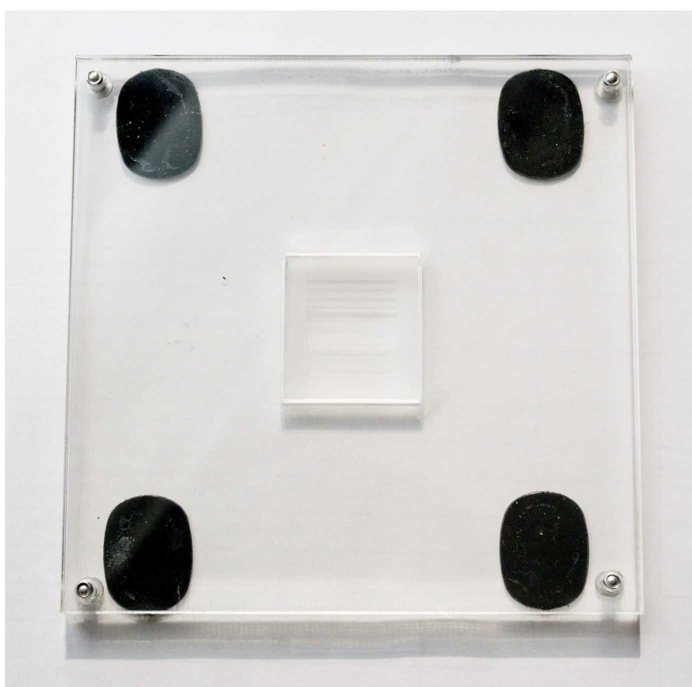

FIGURE 18. TACTILE STIMULUS TILE HOLDER

FIGURE 19. THE CUFF PARTICIPANTS WORE TO RECORD THEIR MOVEMENT

4.4. DESIGN

The experiment consisted of fifty-two trials in total. Each set was presented 3 times (17 sets including the control stimuli x 3). The order of presentation was randomized using the RAND function on excel, that generates an evenly distributed random ordering when associated to a list of items. A trial consisted of exploring the stimulus three times from top to bottom (distal to proximal in relation to anatomical directions)

4.5. PROCEDURE

Participants were given an informed consent form along with a handedness evaluation (see Appendix 3). First, they were shown a set of the tiles that were used for the experiment and were asked to seat comfortably in a chair in front of a table were the tile-apparatus was placed in front of them at the same location. Second, they started a training session that consisted of one control tile and four other tiles with different thicknesses and positions. They were instructed to explore the stimulus starting from the top to the bottom three times using their fingertip of their dominant hand (based on the handedness test). They were asked to not use their fingernail and were asked to always keep the same direction and avoid tilting the finger or finishing the exploration until the last (groove or ridge). The participants were timed but they instructed to explore the stimulus at their own pace. The task was to detect the presence or the absence of the intruder, and when present, to name the position number (which ridge number the intruder was located) Participants were blindfolded and received feedback about their answers. During the experiment, the participants were wearing the cuff to record their hand movements. The experimenter placed the participants' index finger on the first line of the stimulus to start the exploration they explored each stimulus three times by dragging their index finger from the top to the bottom. After the exploration, they had to give their answer, i.e. the presence or absence of the intruder and if present the ridge position. The experimenter wrote down participants' answer and the completion time for each trial. A break of 10 seconds was given between each trial to prevent sensory adaptation to the stimuli.

4.6. ANALYSIS

A two-way repeated measures ANOVA with the factors thickness and position was used on participants' correct answers and completion time. Only significant results were reported.

4.7. RESULTS

4.7.1. PROBABILITY OF RESPONDING CORRECTLY

The probability of responding correctly corresponds to whether the participants detect the presence or absence of the intruder. Mauchky's test indicated that the assumption of sphericity had been violated for the main effects of thickness, χ^2 (5) = 24.13, $p < .001$. Therefore, degree of freedom was corrected using Greenhouse-Greisser estimates of sphericity (ε = .52). There was a significant main effect the factor thickness, $F(1.57, 21.95) = 27.03$, $p < .001$. Pairwise comparisons for the factor thickness show significant differences (Table 1) between all thicknesses except for Thi4 (thickness of 4 mm) and Thi5 (thickness of 5mm). As shown by Figure 20, the wider the stimuli, the better chance it had of being detected. Performances were affected by smaller thickness values. However, participants performed better for Thi4 and higher.

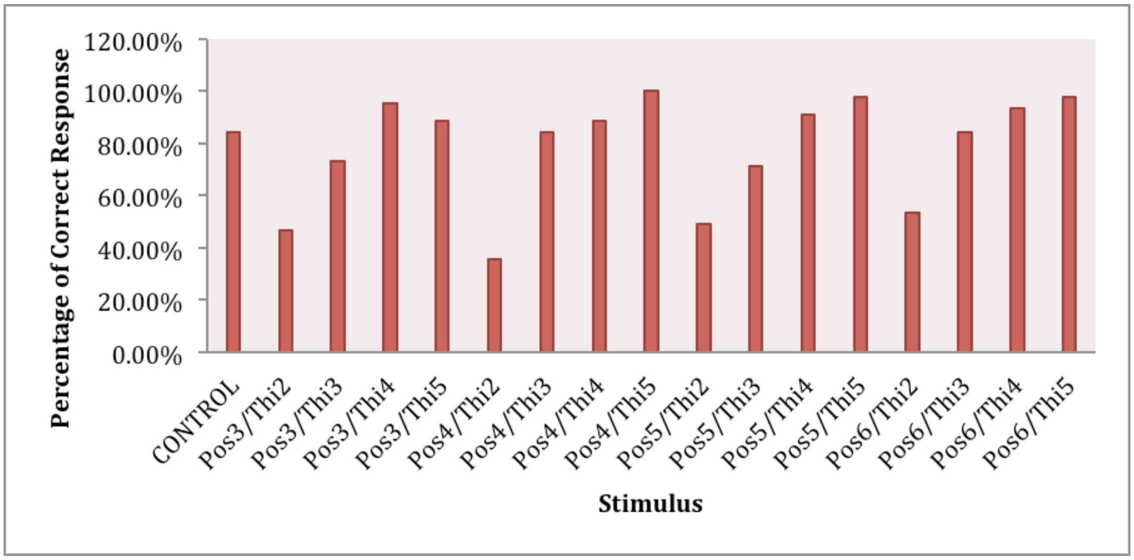

FIGURE 20. PERCENTAGE OF CORRECT RESPONSES PER STIMULUS

TABLE 1. PAIRWISE COMPARISONS FOR THICKNESS FOR CORRECT ANSWERS

Thickness	Thickness	p
Thi2	Thi3	.008
Thi2	Thi4	.001
Thi2	Thi5	.001
Thi3	Thi4	.035
Thi3	Thi5	.003

4.7.2. ERROR RATE

In order to understand participants' responses, we analyzed the error rate. The error, that can be none (NE), one position off (1E), two positions off (2E), or three or higher (3E+), differs according to the position and thickness factors. The none-error consists of participants' correct answers on the position of the intruder. The one position off error represents the rate of incorrect answers when the participants mistaken the position by one line. Similarly, the two positions off error represents the rate of incorrect answers when participants opt for a line that is two lines off of the intruder line. Lastly the three-position error denotes the rate of incorrect answers when the participants picked a line that was three or more lines away from the intruder line. It is important to point out that making an error of type 1E means being closer to the correct position of the intruder. In other words, the larger the error relatively to the intruder position, the less accurate the participants' sensibility to the task.

a. None-Error

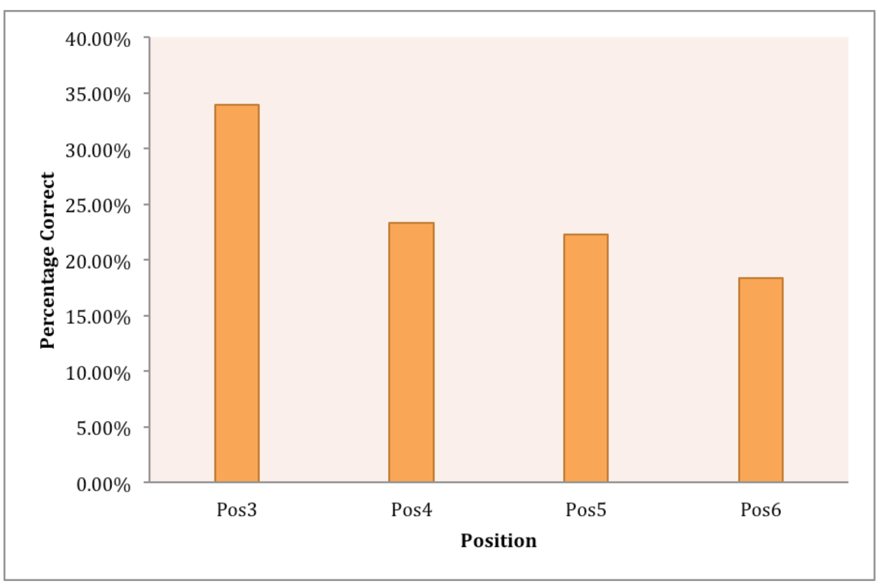

FIGURE 21. PERCENTAGE OF CORRECT RESPONSES FOR POSITION

For Non-Error Mauchky's test indicated that the assumption of sphericity was not violated ($p > .05$). The two-way repeated measures ANOVA with two factors position and thickness showed significant effect of the main factor position $F(3, 42) = 4.93$, $p < .05$. Pairwise comparisons for the main effect position using a Bonferroni adjustment indicate significant difference between Pos3 and Pos6 ($p < .05$). Indeed as shown on Figure 21, participants had less difficulty identifying the intruder position when this later was located at the beginning of the grating (Pos3), as opposed to a central position on the grating (Pos6).

There was also a significant main effect of the factor thickness, $F(3, 42) = 12.02$, $p < .001$. Pairwise comparisons for the main effect thickness, revealed that Thi2 was significantly different from Thi4 ($p < .001$) and Thi5 ($p<.05$), and there was a significant difference between Thi3 and Thi4 ($p <.05$). Figure 22 clearly shows that less errors were made for thicknesses higher than 4 mm, while identifying the correct position of the intruder was clearly affected for 2mm and 3 mm thicknesses.

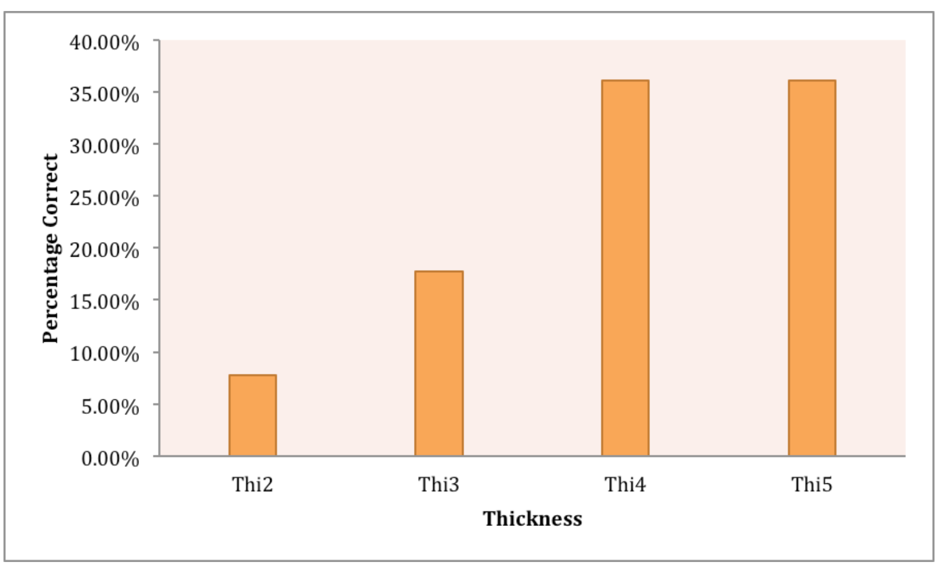

FIGURE 22. PERCENTAGE OF CORRECT RESPONSES FOR THICKNESS

b. Error Rate One

For error 1E, the sphericity was assumed as Mauchky's test was not violated ($p > .05$). The two-way repeated measures ANOVA with the factors position and thickness showed significant effect for thickness, $F(3, 42) = 11.61$, $p < .001$. Pairwise comparisons for the main effect thickness using a Bonferroni adjustment indicated Thi2 was significantly different from Thi3 ($p < .05$), Thi4 ($p < .001$), and Thi5 ($p < .05$). Figure 23 shows clearly that participants' errors rate 1E was higher for small thicknesses comparing to larger thicknesses. This suggests that when thicknesses are higher than 4 mm, participants' answer approximates the correct intruder position by one digit.

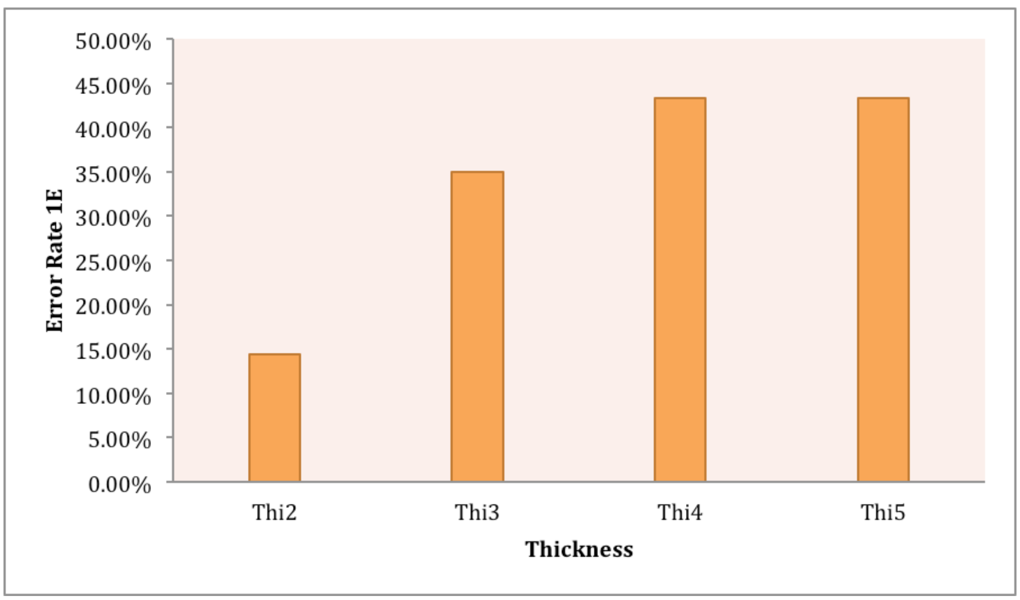

FIGURE 23. ERROR RATE 1E FOR THICKNESS

c. Error Rate Two

Mauchky's test was assumed for error 2E. There was a significant main effect for the factor position, $F(3, 42) = 4.13$, $p < .05$. Pairwise comparisons for the main effect position revealed that Pos3 was significantly different from Pos5 ($p < .05$) and Pos6 ($p < .05$). As shown on Figure 24, participants' error rate 2E is smaller for positions (Pos3) at the beginning of the grating than the central positions (Pos5 and Pos6). This suggests that detecting more accurately the intruder requires a position at the beginning of the grating.

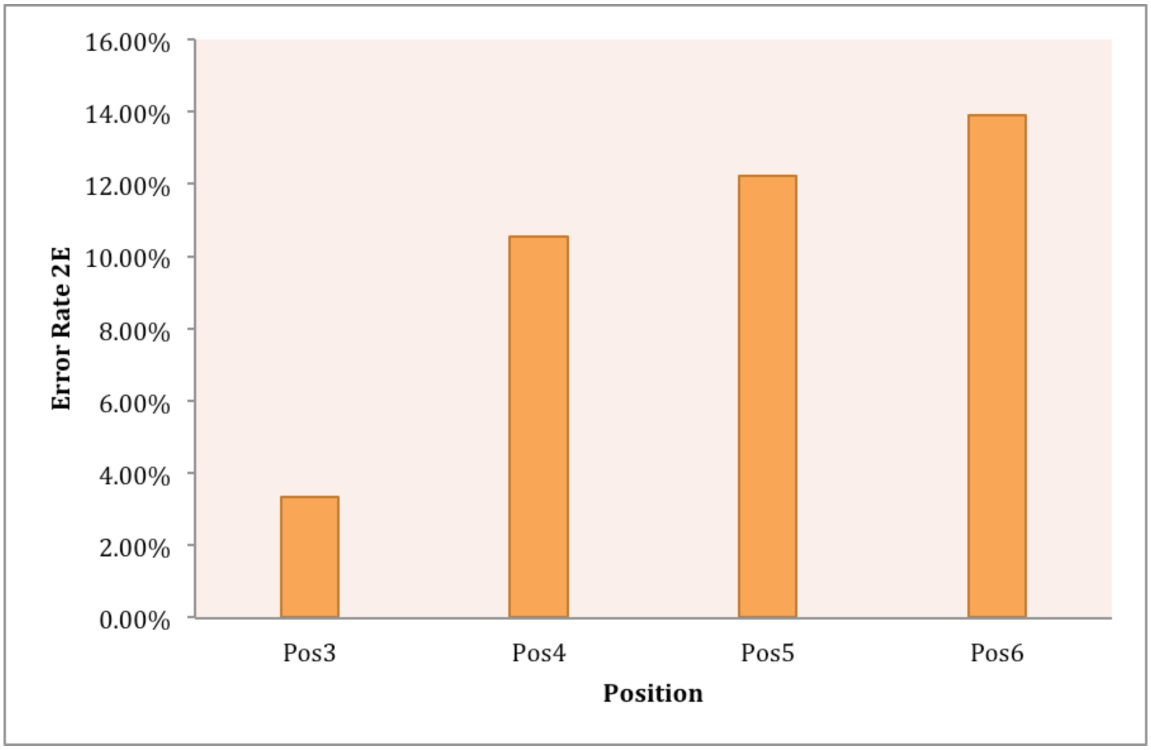

FIGURE 24. ERROR RATE 2E FOR POSITION

d. Error Rate three or Higher

For error 3E+, Mauchky's test indicated that the assumption of sphericity had been violated for the main effect of position, $\chi2$ (5) = 28.84, $p < .001$. Therefore degree of freedom was corrected using Greenhouse-Greisser estimates of sphericity ($\varepsilon = .67$). There was a significant main effect of the factor position, $F(2.01, 28.16) = 7.93$, $p < .05$. Pairwise comparisons for the main effect position using a Bonferroni adjustment indicated that Pos3 is significantly different from Pos5 ($p < .05$) and Pos6 ($p < .05$). Pos4 was also significantly different from Pos5 ($p < .05$) and Pos6 ($p < .05$). As shown by Figure 25, an intruder seems to be more difficult to detect when its position is closer to the end of the grating.

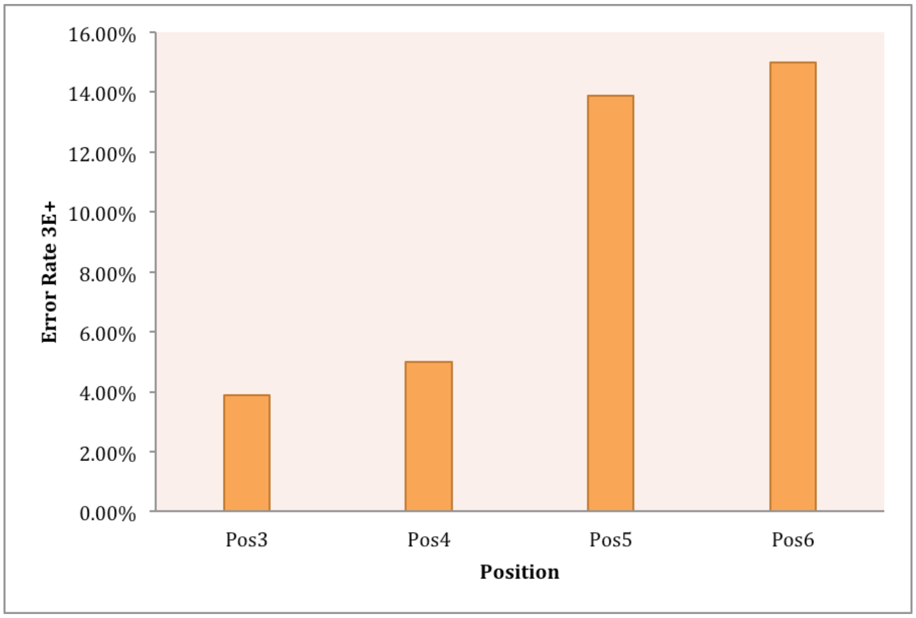

Figure 25. Error rate 3E+ for position

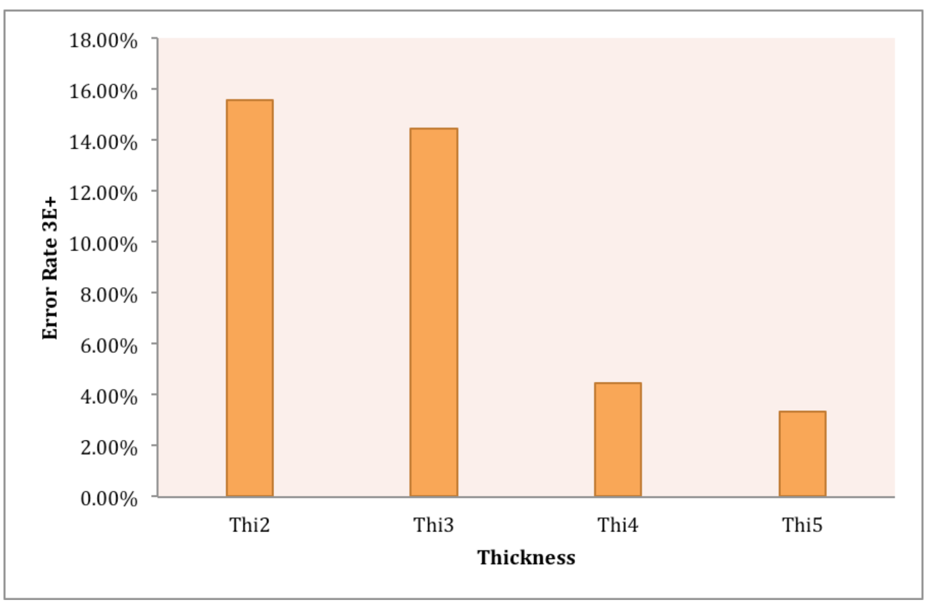

Figure 26. Error rate 3E+ for thickness

For the factor thickness, the sphericity was assumed and Mauchky's test was not violated ($p > .05$). There was also a significant main effect the factor thickness, $F(3, 42) = 6.33$, $p < .001$. Pairwise comparisons for the main effect thickness using a Bonferroni adjustment indicated that Thi2 was significantly different from Thi4 ($p < .05$) and Thi5 ($p < .05$). Thi3 was also a significantly different from Thi4 ($p < .05$) and Thi5 ($p < .05$). Figure 26 shows that there the error rate 3E+ was higher when the intruder thickness was smaller (2 mm and 3 mm).

4.7.3. COMPLETION TIME

The completion time consists of the amount of time required for participants to explore the stimulus. Two-way ANOVA showed a significant interaction effect between the factors position and the thickness, $F(9, 126) = 2.27$. To break down this interaction, simple contrasts were performed. These revealed significant interactions between Pos3 and Pos4, while comparing Thi2 and Thi3, $F(1, 14) = 8.97$, $r = .62$. It also showed a significant effect between Pos3 and Pos5, when comparing Thi2 and Thi3mm to 2mm, $F(1, 14) = 9.96$, $r = .64$. Finally, There was a significant interaction between Pos3 and Pos6 for Thi2 comparing to Thi3, $F(1, 14) = 7.73$, $r = .60$.. As depicted on Figure 27, this indicates that position 3 is different from the others positions (4, 5, and 6), for thicknesses 2 and 3 mm. Indeed, participants' completion time were shorter for Pos3 for Thi3 than Thi2, while an opposite trend was observed for the other positions (shorter completion time for Thi2 than Thi3).

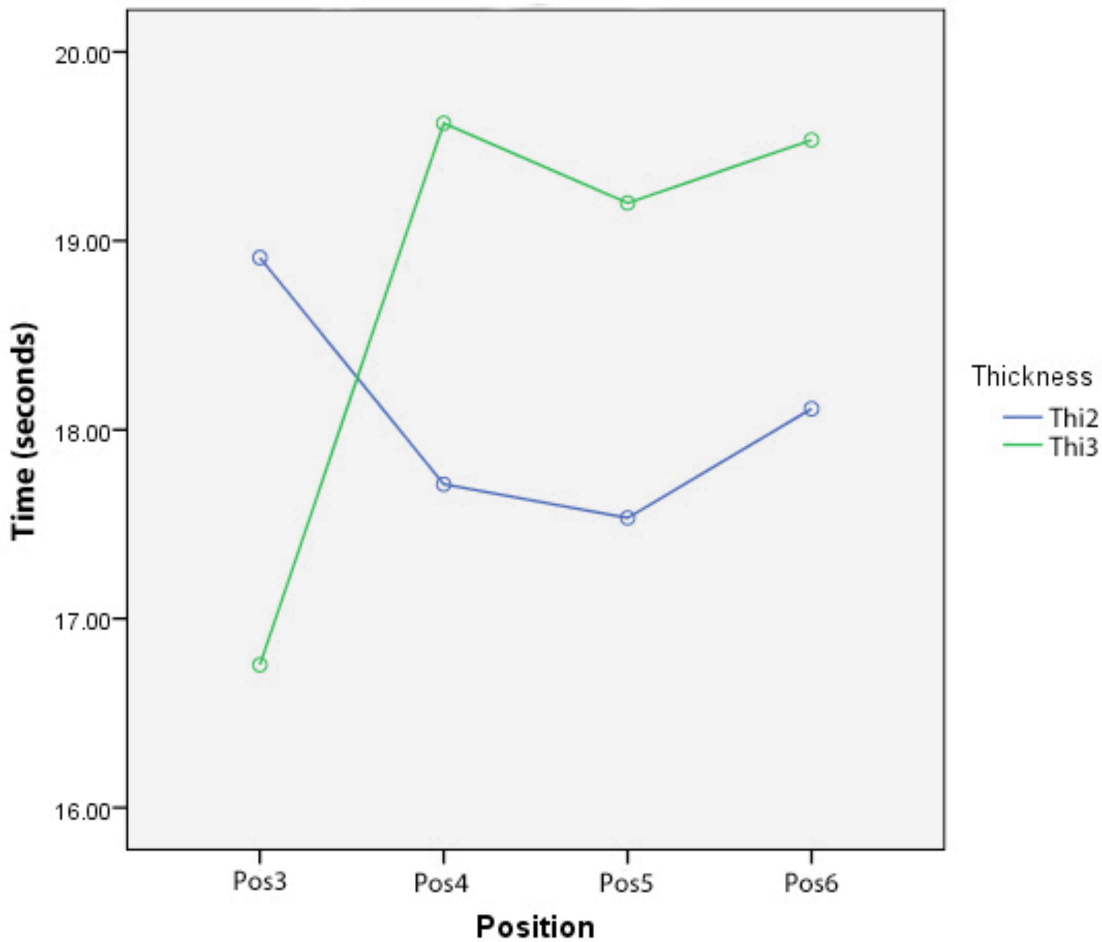

FIGURE 27. INTERACTION OF THICKNESS AND POSITION PLOT

4.8. DISCUSSION

The results showed that both factors position and thickness affected participants' performances and completion time. Participants had higher performance rates for larger thicknesses compared to smaller thicknesses and made larger errors on the intruder position for thinner thickness compared to wider thicknesses. The position of the intruder seemed to play a role, as it was easier to detect the correct position of the intruder when it was located at the beginning of the grating as opposed to the middle of the grating. Finally, participants' completion time was shorter for higher thicknesses for the first position (Pos3). It is possible that because Thi2 was at the beginning of the grating and was barely noticeable, participants slide over the stimulus quickly. To confirm this possibility we will be analyzing participants' movements recorded during the experiment. Although the minimum thickness used in this experiment was 2mm, was above the grating threshold of 1.16 mm (Craig, 1999) for static acuity measurement and 0.8mm for active exploration (Nerfs, 2002), participants spatial segregation was clearly affected by the size of the grating. That said, it is important to point out that during an active spatial acuity measurement, participants have only to determine the orientation of the gratings, while in our task, they have been asked whether they could spatially identify or segregate the outsider. It was possible that the threshold would be higher for more precise task as the one suggested in this thesis. In summary, spatial acuity experiments are more concerned about the orientation of the stimulus rather than detecting the nature of the stimulus.

Another plausible explanation is that an intruder at position 5 or 6 is close to the digit memory span (Miller, 1956) and could be cognitively overwhelming for the participant to keep track of the number. Other tests should be performed in the future to validate this explanation. This idea could carry over to the tactile sense when trying to count gratings.

CONCLUSION

This thesis presented a multidisciplinary approach for perception research. We combined human centered design, computer science, and psychology to explore several interesting subjects that improve our current understanding of the way humans interact with the world and their surrounding environment.

The apparatuses used for the three research projects have all been designed during my master thesis to answer research questions related to personal space, haptic hallucination, and tactile spatial segregation. My previous knowledge in ergonomics, machinery, and prototyping helped me to reach this goal.

The InGrid project, based on the concept of the peripersonal space, could be extended to fit the needs of a specific population such young children or elderly. For instance, InGrid could be used to address creativity in gifted K8 children by measuring reaction time, pauses, and speed of motion that could provide an accurate indication on mental processes during learning scenarios. An innovative aspect of InGrid allows cooperation in a private mode: Children could collaborate using their own touch-screen tablets (private space) and have control over the shared aspect (space of interaction). This setup is advantageous because it avoids limiting creativity, which can sometimes be the case in cooperative learning where emotional aspects, personality trends, and team homogeneity can affect the individual's learning. Most importantly, measurements will be transparent to the child and therefore not interfere with learning while creating. We could assume that lower error rates along with faster reaction time and faster movement would be observed in highly talented children. Another possibility would consist of using InGrid to study passive and active participation in a collaborative setting. This could be executed by having participants passively observe either other users interacting with a two-dimensional map of a campus or actively navigating on their own touch-screen tablets. Their map learning can be later evaluated by assessing their 2D transposing to a three-dimensional navigation of the same campus.

The design of the haptic hallucination sleeve was challenging because it requires adapting the system for electrophysiological measurement. Indeed, one of the main constraints was to ensure that the electronic part is separated from the stimuli part to avoid to any electrical signals being recorded by the Electroencephalograph (EEG), as the EEG could pick-up the signal and could create interference with brain signals. We were hoping that the device could be used in the future to shed the light on neural substrate of Haptic Hallucinations.

Finally, for the tactile spatial segregation task We showed not only the possibility of using human centered design techniques to fabricate the tactile stimulus and cuff, but most interestedly, results that advance our knowledge of tactile segregation while interacting with detailed texture. We are currently running a second experiment to identify the effect of medial-lateral exploration. Indeed the direction of the movement could affect the perceptual threshold. The cuff-system used to record the movements is inexpensive and will allow us to analyze the data in the future using MATLAB. Other possible variation of the experiment includes changing the depth of grooves, the spacing of the gratings, the orientation of the stimulus, the number of intruders, and the amount of time/speed to explore the stimulus.

REFERENCES

Baker, H. S. (1966). *Furniture in The Ancient World* (First American Edition edition.). A Giniger Book in association with The Macmillan Co.

Berrios, G. E. (1982). Tactile hallucinations: conceptual and historical aspects. *Journal of Neurology, Neurosurgery & Psychiatry*, *45*(4), 285–293. doi:10.1136/jnnp.45.4.285

Blom, J. D., & Sommer, I. E. C. (2012). Hallucinations of Bodily Sensation. In J. D. Blom & I. E. C. Sommer (Eds.), *Hallucinations* (pp. 157–169). Springer New York. Retrieved from http://link.springer.com/chapter/10.1007/978-1-4614-0959-5_13

Caggiano, V., Fogassi, L., Rizzolatti, G., Thier, P., & Casile, A. (2009). Mirror Neurons Differentially Encode the Peripersonal and Extrapersonal Space of Monkeys. *Science*, *324*(5925), 403–406. doi:10.1126/science.1166818

Costantini, M., Ambrosini, E., Sinigaglia, C., & Gallese, V. (2011). Tool-use observation makes far objects ready-to-hand. *Neuropsychologia*, *49*(9), 2658–2663. doi:10.1016/j.neuropsychologia.2011.05.013

Craig, J. C. (1999). Grating orientation as a measure of tactile spatial acuity. *Somatosensory & Motor Research*, *16*(3), 197–206. doi:10.1080/08990229970456

Craig, J. C., & Johnson, K. O. (2000). The Two-Point Threshold Not a Measure of Tactile Spatial Resolution. *Current Directions in Psychological Science*, *9*(1), 29–32. doi:10.1111/1467-8721.00054

De Leon, J., Antelo, R. E., & Simpson, G. (1992). Delusion of parasitosis or chronic tactile hallucinosis: Hypothesis about their brain physiopathology. *Comprehensive Psychiatry*, *33*(1), 25–33. doi:10.1016/0010-440X(92)90075-2

De Preester, H. (2010). Technology and the Body: the (Im)Possibilities of Re-embodiment. *Foundations of Science*, *16*(2-3), 119–137. doi:10.1007/s10699-010-9188-5

Encyclopedia Britannica. (2013). *Britannica Academic Edition*. Retrieved November 4, 2013, from http://www.britannica.com/EBchecked/topic/287847/information-processing/61653/Acquisition-and-recording-of-information-in-analog-form?anchor=ref212036

Fellner, M. J. (2012). New findings in delusions of parasitosis. *Skinmed*.

Geyer, F., Budzinski, J., & Reiterer, H. (2012). IdeaVis: A Hybrid Workspace and Interactive Visualization for Paper-based Collaborative Sketching Sessions. In *Proceedings of the 7th Nordic Conference on Human-Computer Interaction: Making Sense Through Design* (pp. 331–340). New York, NY, USA: ACM. doi:10.1145/2399016.2399069

Geyer, F., Pfeil, U., Budzinski, J., Höchtl, A., & Reiterer, H. (2011). AffinityTable - A Hybrid Surface for Supporting Affinity Diagramming. In P. Campos, N. Graham, J. Jorge, N. Nunes, P. Palanque, & M. Winckler (Eds.), *Human-Computer Interaction – INTERACT 2011* (pp. 477–484). Springer Berlin Heidelberg. Retrieved from http://link.springer.com/chapter/10.1007/978-3-642-23765-2_33

Goldreich, D., & Kanics, I. M. (2006). Performance of blind and sighted humans on a tactile grating detection task. *Perception & Psychophysics*, *68*(8), 1363–1371. doi:10.3758/BF03193735

Goldreich, D., Wong, M., Peters, R. M., & Kanics, I. M. (2009). A Tactile Automated Passive-Finger Stimulator (TAPS). *Journal of Visualized Experiments*, (28). doi:10.3791/1374

Hayward, C. H. (1979). *Antique furniture designs*. New York: C. Scribner's Sons.

Hinkle, N. C. (2000). Delusory Parasitosis. *American Entomologist*, *46*(1), 17–25.

Holz, C., & Baudisch, P. (2010). The Generalized Perceived Input Point Model and How to Double Touch Accuracy by Extracting Fingerprints. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (pp. 581–590). New York, NY, USA: ACM. doi:10.1145/1753326.1753413

Hylwa SA, Bury JE, Davis MP, Pittelkow M, & Bostwick J. (2011). Delusional infestation, including delusions of parasitosis: Results of histologic examination of skin biopsy and patient-provided skin specimens. *Archives of Dermatology*, *147*(9), 1041–1045. doi:10.1001/archdermatol.2011.114

IKEA. (2013). Retrieved November 11, 2013, from http://www.ikea.com/ms/en_US/about_ikea/the_ikea_way/our_business_idea/our_product_range.html

Ishibashi, H., Hihara, S., & Iriki, A. (2000). Acquisition and development of monkey tool-use: behavioral and kinematic analyses. *Canadian Journal of Physiology and Pharmacology*, *78*(11), 958–966. doi:10.1139/y00-063

Krumbholz, C., Leigh, J., Johnson, A., Renambot, L., & Kooima, R. (2005). Lambda table: high resolution tiled display table for interacting with large visualizations. In *Proceedings of 5th Workshop on Advanced Collaborative Environments, Redmond, Washington*. Retrieved from http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.66.4528&rep=rep1&type=pdf

Larousse. (2013). *Larousse*. Retrieved November 4, 2013, from http://www.larousse.com/en/dictionaries/french/tablette/76309?q=tablette#75424

Lenay, C. (2012). Separability and Technical Constitution. *Foundations of Science*, *17*(4), 379–384. doi:10.1007/s10699-011-9245-8

Low, S. M. (2003). Embodied Space(s) Anthropological Theories of Body, Space, and Culture. *Space and Culture*, *6*(1), 9–18. doi:10.1177/1206331202238959

Merriam Webster Dictionary. (2013). *Merriam-Webster.com*. Retrieved September 9, 2013, from http://www.merriam-webster.com/dictionary/tablet

Miller, G. A. (1956). The magical number seven, plus or minus two: some limits on our capacity for processing information. *Psychological Review*, *63*(2), 81–97. doi:10.1037/h0043158

Morley, J. W., Goodwin, D. A. W., & Darian-Smith, I. (1983). Tactile discrimination of gratings. *Experimental Brain Research*, *49*(2), 291–299. doi:10.1007/BF00238588

Muller-Tomfelde, C. (2010). *Tabletops - Horizontal Interactive Displays*. Retrieved from http://www.springer.com/computer/hci/book/978-1-84996-112-7

Nefs, H. T., Kappers, A. M., & Koenderink, J. J. (2002). Frequency discrimination between and within line gratings by dynamic touch. *Perception & Psychophysics*, *64*(6), 969–980.

Nefs, H. T., Kappers, A. M. L., & Koenderink, J. J. (2001). Amplitude and spatial-period discrimination in sinusoidal gratings by dynamic touch. *Perception*, *30*(10), 1263–1274. doi:10.1068/p3217

O'Regan, J. K., & Noë, A. (2001). A sensorimotor account of vision and visual consciousness. *Behavioral and Brain Sciences*, *24*(05), 939–973. doi:10.1017/S0140525X01000115

Postell, J. C. (2007). *Furniture design*. Hoboken, N.J: John Wiley & Sons.

Prince, J. D. (2011). A Dictionary of Hallucinations. *Journal of the Medical Library Association : JMLA*, *99*(3), 262–263. doi:10.3163/1536-5050.99.3.016

Seifried, T., Rendl, C., Perteneder, F., Leitner, J., Haller, M., Sakamoto, D., … Scott, S. D. (2009). CRISTAL, Control of Remotely Interfaced Systems Using Touch-based Actions in Living Spaces. In *ACM SIGGRAPH 2009 Emerging Technologies* (pp. 6:1–6:1). New York, NY, USA: ACM. doi:10.1145/1597956.1597962

SIEGEL, K. (1978). Cocaine Hallucinations. *Am J Psychiatry*, *135*(3). Retrieved from http://journals.psychiatryonline.org/data/Journals/AJP/3100/309.pdf

Siegel, R. K. (1982). Cocaine Smoking. *Journal of Psychoactive Drugs*, *14*(4), 271–359.

Spindler, M., Martsch, M., & Dachselt, R. (2012). Going Beyond the Surface: Studying Multi-layer Interaction Above the Tabletop. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (pp. 1277–1286). New York, NY, USA: ACM. doi:10.1145/2207676.2208583

Zhang, H., Yang, X.-D., Ens, B., Liang, H.-N., Boulanger, P., & Irani, P. (2012). See Me, See You: A Lightweight Method for Discriminating User Touches on Tabletop Displays. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (pp. 2327–2336). New York, NY, USA: ACM. doi:10.1145/2207676.2208392

Ziat, M. (2007). Zoomable experience. Retrieved from http://www.researchgate.net/publication/255823151_Zoomable_Experience/file/3deec520d169f0e422.pdf

Ziat, M., Gapenne, O., Lenay, C., & Stewart, J. (2005). Perception in numerical and corporeal spaces in a 2D haptic virtual world. *ENACTIVE'05*. Retrieved from http://www.researchgate.net/publication/233427397_Perception_in_numerical_and_corporeal_spaces_in_a_2D_haptic_virtual_world/file/79e4150e9c7e161d7a.pdf

Ziat, M., Gapenne, O., Lenay, C., & Stewart, J. (2007). Zooming experience in the haptic modality. *ENACTIVE'07*, 305–308.

Ziat, M., Gapenne, O., Stewart, J., & Lenay, C. (2006). Haptic recognition of shapes at different scales: A comparison of two methods of interaction. *Interacting with Computers*, *19*(1), 121–132. doi:10.1016/j.intcom.2006.07.004

APPENDIX 1

Memorandum

TO: Mounia Ziat

Psychology Department

CC: Jon Fancher

Erin Smith

Candace Calvetti

FROM: Brian D. Cherry, Ph.D.

Assistant Provost

DATE: March 18, 2014

SUBJECT: IRB HS11-437 Modification and Extension

"Effects of Ebbinghaus Illusion on Touch"

New IRB Approval Dates: 12/5/2011-12/5/2014

Your extension and modification request for IRB HS11-437 "Effects of Ebbinghaus Illusion on Touch" has been PARTIALLY approved under the administrative review process.

Approved:

- One-year extension.
- Change in researcher from Cecilia Brown to Candance Calvetti.
- Add researcher Jon Fancher.
- Change in stimulus.

Not approved:

- Change in title. A title change requires a new submission.

Please include your proposal number (HS11-437) on all research materials and on any correspondence regarding this project.

Any additional changes or revisions to your approved research plan must be approved by the IRB prior to implementation. Unless specified otherwise, all previous requirements included in your original approval notice remain in effect.

APPENDIX 2

NORTHERN MICHIGAN UNIVERSITY

INFORMED CONSENT STATEMENT

Title of Project: Tactile Temporal Recognition and Discrimination

Investigators:Dr. Mounia Ziat (Assistant Professor, Department of Psychology, NMU)

Jon Fancher (Graduate research assistant, Department of Psychology, NMU)

Samantha Wagner (Graduate research assistant, Department of Psychology, NMU

You are invited to participate in a research study. The purpose of this experiment is to study tactile perception. Either Jon Fancher or Samantha Wagner, research assistants at Northern Michigan University will be conducting the study under the advisory of Dr. Mounia Ziat.

INFORMATION

Fifteen people will be asked to participate in this experiment, which will consist of one session that is about 40 minutes. Participants must be of either gender and between the ages of 18 and 55. You will be asked to wear a blindfold and explore acrylic tiles in front of you. The figure will be a set of ten evenly spaced lines that has an intruder with a different thickness than the rest of the lines. The task is to explore with your index finger and decide if you can detect the intruder line and if you can detect it decide if what number line it is. You have two passes from top to bottom to explore the figure and then give your answer verbally to the experimenter. The experimenter notes your answer and you will start the next trial after a ten second break.

RISKS

There are no known risks associated with participation in this study.

BENEFITS

There are no direct benefits to the participants other than research experience and the satisfaction of contributing to scientific knowledge. We anticipate that the scientific community will benefit from a better understanding of sensation and perception. Society at large also stands to benefit from the results of this study, as it will advance basic knowledge of the perceptual systems that are used in any interaction with the environment.

CONFIDENTIALITY

The data collected from participants will be stored on a computer in a secure lab using their initials only. The consent forms and participants' names will be stored in a locked filing cabinet in Dr. Ziat's lab separate from the coded data. Arbitrary code numbers will be used to differentiate between participants (if necessary) in any resultant publications or presentations. Only Dr. Ziat, Jon Fancher, and Samantha Wagner will have direct access to the data, consent forms, or participant lists. Material will be kept until full analysis of the data has been completed and the research has been published. All electronic files will be erased and hardcopies shredded no longer than 7 years after the completion of the study (by November 2018).

COMPENSATION (Only for psychology students)

If you choose to participate in this study, you may earn extra credit in your course in alternate ways. Please consult your instructor.

CONTACT

If you have questions at any time about the study or the procedures, or you experience adverse effects as a result of participating in this study, you may contact the principal investigator, Mounia Ziat (mziat@nmu.edu and 227-2948) in the Department of Psychology, Northern Michigan University. This project has been reviewed and approved by the University Research Ethics Board at Northern Michigan University. If you feel you have not been treated according to the descriptions in this form, or your rights as a participant in research have been violated during the course of this project, you may contact the IRB chair (dereande@nmu.edu) and NMU's IRB administrator (tseethof@nmu.edu).

PARTICIPATION

Your participation in this study is voluntary; you may decline to participate without penalty. If you decide to participate, you may withdraw from the study at any time without penalty and without loss of benefits to which you are otherwise entitled. If you withdraw from the study before data collection is completed your data (if part of data is collected) will be returned to you or destroyed by either Pr. Mounia Ziat, Jon Fancher, or Samantha Wagner. You have the right to omit any question(s)/procedure(s) you choose.

FEEDBACK AND PUBLICATION

The results of the research may be published in journal articles, and other scientific conferences and university colloquia. If you wish, the results of this study will be e-mailed to you no later than May 1, 2014.

I have read and understand the above information. I have received a copy of this form. I agree to participate in this study.

Participant's signature ______________________ email______________________

Date________________ Age__________________ Gender______________________

Investigator's signature_________________________________ Date ________________

APPENDIX 3

Handedness Questionnaire

Most people are either right-handed or left-handed. However, there are different "degrees" of handedness. Some people use one hand for jobs that require skill and the other hand for jobs that involve reaching. Other people use the same hand for these different jobs. Use this "Handedness Questionnaire" to measure the strength of handedness. Place a mark in a box for each question that describes you best.

	LEFT Hand	RIGHT Hand	EITHER Hand
1. Which hand do you use to write?			
2. Which hand do you use to draw?			
3. Which hand do you use to throw a ball?			
4. Which hand do you hold a tennis racket?			
5. With which hand do you hold a toothbrush?			
6. Which hand holds a knife when you cut things?			

7. Which hand holds a hammer when you nail things?			
8. Which hand holds a match when you light it?			
9. Which hand holds an eraser when you erase things?			
10. Which hand removes the top card when you deal from a deck?			
11. Which hand holds the thread when you thread a needle?			
12. Which hand holds a fly swatter?			
TOTAL			