Skinscape: A Tool for Composition in the Tactile Modality

by Eric Gunther

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Author _____

Department of Electrical Engineering and Computer Science May 23, 2001

Certified by _____

Glorianna Davenport, Principal Investigator, Interactive Cinema Group, MIT Media Laboratory Thesis Advisor

Certified by ______ Sile O'Modhrain, Post Doctoral Fellow, MIT Media Laboratory

Thesis Advisor

Accepted by _____

Arthur C. Smith Chairman, Department Committee on Graduate Theses

Abstract

The sense of touch has been relatively unexplored as a compositional medium. This raises the question: Is the skin capable of understanding and ultimately appreciating complex aesthetic information? Evidence from a number of psychophysical studies on the sense of touch suggests that it is. The technology for tactile composition is currently available: the possibilities for applying this technology in an artistic context have presumably been overlooked. Hence, this paper represents a shift in focus toward more abstract applications of haptic and tactile stimulation technology. Tactile composition is approached as a multi-modal activity involving the senses of hearing and touch – essentially "cutaneous choreography" to music. The use of several psychophysical dimensions of tactile stimuli as basic vocabulary elements in a compositional language for the sense of touch is investigated. A number of theoretical issues surrounding tactile composition are explored, including cross-modal interactions between audition and touch, the affective response to tactile composition, and the feasibility of exclusively tactile composition. The design and functionality of a system that facilitates composition in the tactile modality is described. The system consists of a vibrotactile stimulator capable of delivering a wide range of spatio-temporal patterns to the surface of the body, as well as a software / hardware control system and a software composition environment which allows a user to compose for the device along with a previously recorded audio track. Initial tests of the system demonstrate its ability to generate aesthetically pleasing, perceptually engaging tactile compositions. The potential applications for this technology are myriad. Tactile composition has especially far reaching implications for the hearing impaired community and for immersive cinema.

Thesis Advisor: Glorianna Davenport, Professor of Media Arts and Sciences, Principal Investigator, Interactive Cinema Group, MIT Media Laboratory

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1 Introduction

The skin is the largest organ system of the body, about $2,500 \text{ cm}^2$ in the newborn and about 18,000 cm² in the average male, and constitutes about 16 to 18 percent of total body weight (Montagu, 1971). Touch is considered by many to be the most important of our senses, for without it we can have no sense of the physical boundaries of our own bodies or our surrounding physical environment. In his De Anima, Aristotle proposed that without touch it is impossible to have any other sense, for every body that has a soul in it must be capable of touch. During the early stages of life in the womb, the tactile sense is the first to develop. The sense of touch is indispensable for the creation of all kinds of artistic artifacts. Why then, do we generally deny our sense of touch the opportunity to *behold* artistic expression? Our senses of sight and hearing have been channels of artistic expression for centuries. Throughout history, visual art and music have been nurtured and explored by the human spirit and continue to evolve. Coppola (1971) speaks of a perceptual prejudice, pointing out that philosophy, physics and even psychology have always relied overwhelmingly on visual evidence to interpret the world¹. This prejudice against touch is also evident in the art world. What makes the eyes and ears so special that they can enjoy artistic creation while the skin cannot? There have been isolated efforts throughout history to artistically engage the sense of touch, but the skin has not been explored - in a manner analogous to music for the ears - in any considerable depth as a medium for aesthetic composition. Why is this so? There are a number of possible reasons.

First, our sense of touch is inherently different from, say, our sense of hearing. Any number of simple implements for making sound can be combined to produce complex and interesting sonic compositions. In addition, these compositions can be experienced by any number of people within audible range of the sound source; there is no requirement for physical contact with the sound receptors of the auditory system. The sense of touch, however, is highly egocentric and consequently, engaging the skin of multiple persons is far more difficult than making music for more than one person. The

¹ Dr. August F. Coppola is the creator of the *Tactile Dome* exhibit at the San Fransisco Palace of Fine arts.

primary factor is that some form of physical contact is required to stimulate the human haptic system. One could argue that the book is an equally egocentric medium. The difference is that books are easier to duplicate because of the advent of printing technology.

The second reason is that the generation of intricate, aesthetically interesting tactile stimulation is no trivial task and necessitates the use of technology. The past century has seen the development of a field of research directed at understanding the human haptic system. During the last thirty years, a more specific area of research often referred to as *computer haptics* has emerged, its primary goal being the design devices capable of haptic and tactile stimulation. However, the design and construction of devices capable of mechanically engaging the haptic system continues to be a difficult problem. Although computer haptics is currently an active field of research which seems to be receiving increasing interest, tactile stimulation technology is without question in the early stages; there is a long way to go before devices capable of engaging the full range of tactile sensations will be available. To compound this issue, the communication link between this area of research and the general public is weak - a large percentage of people are not even familiar with the term "haptics." Bits and pieces of the technology produced by haptics research are beginning to make their way into commercial applications, but are far from being standard components in personal computing systems.

The reader is asked to imagine a computer-controlled, wearable device capable of generating tactile stimulation against the surface of the body. In addition, imagine a software application that allows a person to compose and play back spatio-temporal patterns for this device, which may be experienced alone or choreographed to other forms of media such as music or video. It turns out that this hypothetical system, which facilitates *tactile composition*, is not so far from being realized.

Before proceeding to think about the engineering logistics of designing a tactile composition system, though, we must consider the question: Is the haptic system capable of receiving, processing, understanding, and ultimately appreciating a tactile composition in the way that the auditory system does for music? As a receiving instrument the skin combines the best abilities of the eye and the ear, exhibiting high acuity in both space and time (Geldard, 1966a). A significant body of research aimed at determining the skin's information processing abilities has demonstrated the ability of the human haptic system to understand complex spatio-temporal patterns. These and several other factors contribute to the feasibility of tactile composition.

Albeit the limitations of tactile stimulation devices, the technology for tactile composition is presently available. Historically, it seems that the focus of haptics research has been on the generation of realistic haptic and tactile experiences. The field has become so caught up in trying to 'make it feel real' that the potential for using the technology in an aesthetic context has been overlooked. There have been isolated attempts at applying the technology for aesthetic purposes (Wachpress, 1975; Aura Interactor and BFG Labs Intensor Chair – see Appendix B), but they have been few and relatively limited. Certainly, haptic and music in particular have a long history together that continually evolves with the advance of new technologies. Their relationship has generally been one-way, using haptic interfaces to generate music. Roughly speaking, tactile composition reverses this relationship, using music to generate haptic sensations.

The time is now ripe for the idea of tactile composition. Looking at the evolution of entertainment forms, it appears that society has a hunger for synesthetic (referring generally to cross-modal sensation) experience. Theatre, opera, dance, and the motion picture represent examples of entertainment forms – as well as compositional mediums – that engage multiple senses. There have been scores of other attempts throughout history to expand activities which were historically or culturally limited to a single sense modality. These have taken the form of theme park rides, immersive movies, the infamous *smell-o-vision*, visual music, the music video, and so on. Take for instance, the disco and rave cultures. The lights, sounds, vibrations, and haptic sensations experienced at a nightclub are all indicative of this search for sensory immersion. Tactile composition may represent yet one more dish to satisfy society's craving for synesthetic experience.

In addition, many of the musical genres emerging in recent decades have placed a heavy emphasis on rhythm. Modern electronic dance music is probably the best example. This music is often referred to as 'visceral', engaging the body as much as much as it does the mind. Other forms of music such as rock n' roll and hip-hop might also be classified as music for the body. Along these lines, tactile composition seems to be a natural continuation of one direction in which music has moved over the last half-century. It takes this movement of music toward the body one step further, literally putting it *on* the body. We will also see that the field of music provides a very powerful analogue for tactile composition. Tactile composition may also be viewed as a translation of the traditional notion of dance into the tactile domain - essentially as a "dance for the skin".

This paper begins with some fundamental facts about the sense of touch. We can approach and inform the development of tactile composition from many different angles and paradigms. Chapter Three proposes some of the fields from which we might draw upon. Next, the design and functionality of a prototype system for tactile composition called *Skinscape* is described. The following chapters begin to examine several issues surrounding tactile composition. In Chapter Five we consider how to go about forming a compositional language for the sense of touch, looking specifically at which dimensions of tactile stimuli can be used to form basic compositional vocabulary elements. Chapter Six subsequently discusses several interesting issues that arise during the composition process. Tactile composition involves the simultaneous stimulation of two sensory modalities. The five senses are anything but independent and consequently, there are a number of intersensory interactions. Chapter Seven introduces some of these interactions and begins to examine how they might be harnessed for compositional purposes. There is enormous potential for tactile composition to evoke an emotional response. Chapter Eight begins by reviewing what we know about the affective response to music and then looks at the possible similarities and differences of the affective response to tactile composition. In Chapter Nine, the feasibility of composing exclusively in the tactile modality - without the music - is examined. Last, some additional applications for the idea of tactile composition and its associated technology are suggested and areas for future investigation are proposed.

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2 Background

2.1 Terminology / Definitions

The term *haptics* encompasses all things pertaining to the sense of touch The *haptic system* typically refers to the collective group of anatomical structures which contribute to our sensation of haptic stimuli; this includes both peripheral components as well as those situated within the central nervous system. Haptic sensations can be subdivided into two main channels. The first channel is that of *tactile sensation* (also known as *taction*). Rovan and Hayward explain that this channel is typically associated with the sensation of pressure, local features such as curvature, orientation, puncture, texture, thermal properties, softness, wetness, slip, adhesion, and vibration. The skin is typically designated as the seat of this sense. The second channel is that of *proprioceptive or kinesthetic perception*. This channel constitutes awareness of one's body state, including position, velocity and forces supplied by the muscles through a variety of receptors located in the skin, joints, muscles, and tendons. It is often associated with the limbs, but of course applies to all articulated parts of the body subject to voluntary motor control (2000).

With this distinction out of the way, we can talk about the two classes of devices which engage the sense of touch: *tactile stimulators* and *haptic devices*. The former is comprised of devices which typically simulate the effect of the skin touching a surface. They will often use some mechanism of controlled skin deformation (a matrix of pins for instance) or *vibrotactile stimulators* (devices vibrating at a given frequency, in contact with the skin at one or several locations). In addition to these two examples, there are several other subclasses of tactile stimulators which are discussed in later sections of this paper. The latter class serves as a mediating device through which one explores or manipulates a virtual mechanical system. As the operator moves the haptic device across space, acting as a virtual probe, mechanical feedback is transmitted to simulate the passing of the probe over, against or through a virtual object (Rovan/Hayward, 2000).

The device presented in this paper constitutes a tactile stimulator²; more specifically a vibrotactile stimulator. Consequently, the following sections will be concerned mainly with tactile sensation; in particular, vibrotactile sensation. It should be noted, however, that the taction and proprioception channels are not independent and although a tactile stimulator might only directly engage the taction channel, issues pertaining to proprioception can arise (discussed in more detail in the section titled Compositional issues). What follows is an overview of the physiology and psychophysics of taction.

2.2 Anatomy of the skin

2.2.1 Mechanoreceptors

The sensation produced by mechanical stimulation of the skin is determined by both mechanoreceptor properties and central neural mechanisms. (Kaczmarek *et al.*, 1991). Although the details of the structure and functionality of the central neural mechanisms are still unknown, much is known about the peripheral mechanisms. Tactile sensations - ie the mechanical aspects of touch - can be divided into four channels, each mediated by a specific type of mechanoreceptor in the skin. The four types of receptors are typically categorized in terms of their field of sensitivity, the rate at which they adapt, and their situation within skin layers. Table 2.1 (Kaczmarek *et al.*, 1991) lists several properties of the receptors including receptive field, what type of skin they are found in, frequency range, density and sensitivity on the hand, and sensory correlate. Note that the term *glabrous* is synonymous with non-hairy skin.

 $^{^{2}}$ Often the narrower term *tactile display* is used. It is not used here because *display* gives the connotation of presenting some representation of information.

PROBABLE RECEPTOR	CLASS (STEP INDENTATION RESPONSE)	RECEPTIVE FIELD (mm ²) (MEDIAN)	SKIN TYPE	FREQUENCY RANGE (MOST SENSITIVE)	THRESHOLD SKIN DEFORM ON HAND (MEDIAN)	PROBABLE SENSORY CORRELATE	RECEPTORS/cm ² FINGERTIP (PALM)
PACINIAN CORPUSCLE	FA II (RA IL QA II, PC)	10-1000 (101)	G,H	40-800 Hz (200-300 Hz)	3-20 μm (9.2 μm)	VIBRATION	21 (9)
MEISSNER'S CORPUSCLE	FAI (RALQAL RA)	1-100 (12.6)	G	10-200 Hz (20-40 Hz)	4-500 µm (13.8 µm)	TOUCH TICKLE MOTION VIBR FLUTTER TAP	140 (25)
HAIR FOLLICLE RECEPTOR	FA (RA, QA)	?	H	?	?	TOUCH	-
RUFFINI ENDING	SA II	10-500 (59)	G,H	7 Hz	40-1500 µm (331 µm)	STRETCH SHEAR TENSION (?)	9 (15)
MERKEL'S	SA I	2-100 (11.0)	G	0.4-100 Hz (7 Hz)	7-600 μm (56.5 μm)	EDGE (?) PRESSURE	70 (8)
TACTILE DISKS	SA .	3-50	н	?	2	?	115 - 1
SA: SLOV I: SMALL, * G: GLAE	VADAPTING F DISTINCT FIEL BROUS SKIN H	A: FAST ADAP D II: LARGE, D : HAIRY SKIN	TING.	E FIELD	SOURCE	S: [18], [30], [31] [90], [109], [1 [135], [138], [, [61], [62], [63], 10], [113], [132], 147]

Table 2.1. (Kaczmarek et al., 1991) Summary of mechanoreceptor characteristics

2.2.2 Distribution of receptors in the skin

The density of the receptors throughout the skin is not constant, but rather a function of body location. The homunculus diagram (Montagu, 1971), shown in Figure 2.1, is an intuitive illustration of the distribution of receptors in the skin. Sensitivity is proportional to the size of the body part in the diagram. The three areas with the highest receptor density and thus the most sensitivity are the hands, lips, and genitals.

Verillo points out that differences in receptor density are manifested as differences in threshold sensitivity, suprathreshold function, the potential interference or confusion of signals delivered to different sites, and cosmetic considerations of wearing a tactile device (1992). It is important to consider all of these variables when designing a tactile stimulator; especially one which stimulates multiple body sites.



Figure 2.1. (Montagu, 1971) Sensory homunculus drawn upon the profile of one hemisphere. The underlying sold lines indicate the extent of cortical representation.

2.3 Psychophysics of the sense of touch

Psychophysics is the science of human sensory perception (Millman, 1995).

Traditionally, it has been concerned with reconciling the psychological behavior and the physiology of sensory systems. Below is an overview of several psychophysical dimensions associated with taction³. The implications of each dimension on the system presented in this paper and to tactile stimulators in general are also raised in this section. Psychophysical issues pertinent to the design of a tactile composition system are presented in the section titled Compositional issues.

Lederman explains the function of psychophysical research in the design of haptic interfaces. Scientific information can be used to guide initial design considerations. For

³ Much of the material in this section is referenced from a chapter written by Verrillo and Gescheider (1992) which presents an excellent overview of the sense of touch. The organization of this section is modeled after this chapter as well.

example, the psychophysical results can be used to select appropriate physical parameters and associated values for an interface. Results from basic research on human haptics highlight both the strengths and the limitations of using the haptic system to operate a sensory interface. Such information allows you to match the critical input/output parameters that underlie human processing to the specific demands imposed by some haptic interface system. In general, to avoid subsequent design problems, early consideration of psychophysics will prove very helpful⁴.

The psychophysics of touch also has implications for the composition process. In a highly thoughtful and insightful volume on "the electronic arts of sound and light," Pellegrino writes: The composition of *visual music* is considerably enhanced by the study of psycho-optics, a discipline that integrates optics, human receptor systems, and psychology. One's compositional work is likely to reach more profound levels with the understanding of these fundamental areas. For the composer of light and sound, the related disciplines of psycho-optics and psychoacoustics contain a wealth of information crucial to the expansion and refinement of one's conceptual and perceptual bases for creative activity (1983). This point resonates the potential benefits stemming from a basic understanding of the sensory modality in which one is composing.

2.3.1 Frequency of vibration

The range of the vibrotactile frequency response is roughly 20 - 1000 Hz. This range is very narrow compared to that of the auditory system (20 - 20,000 Hz). This discrepancy must be accounted for when performing cross-modal mappings from audition to taction. It is important to note that the area of contact between the skin and the stimulating device will influence the skin's response to vibrotactile stimuli of different frequencies . Figure 2.2 (Verrillo, 1963) shows the threshold curves as a function of frequency for several contactor sizes. For larger contactors, the curve shows that thresholds are generally independent of frequency at lower frequencies and display a U-shape at higher frequencies. Maximal sensitivity occurs around 250 Hz. Thus operation of a vibrotactile

⁴ Susan J. Lederman, Haptics Community Webpage: http://haptic.mech.northwestern.edu/intro/psychophysics/

stimulator in the locale of 250 Hz will yield the greatest dynamic range. When very small contactors are used ($< 0.02 \text{ cm}^2$), threshold is independent of frequency.



Figure 2.2. (Verrillo, 1963) Thresholds for the detection of vibrotactile stimuli measured as a function of sinusoidal frequency at the thenar eminence of the right hand.

2.3.2 Frequency discrimination

Early studies have established that the skin is, indeed, differentially sensitive to different frequencies of vibration. Studies (indicate studies) also indicate, however, that the skin is rather poor at discriminating frequency differences and that its limited ability to do so decreases as frequency increases (Verrillo and Gescheider, 1992). The anatomy of the haptic system - compared to that of the auditory system which has evolved complex mechanisms for frequency analysis – does not include specialized mechanisms for frequency discrimination. Consequently, the role of frequency as a modulated dimension of tactile stimuli usually assumes less importance in the transmission of information on a tactile stimulator. This scenario is very different from say, music, in which the frequency of auditory stimuli (i.e. pitch) is a crucial perceptual dimension for conveying musical information.



Figure 2.3. (Sherrick, 1985) Log of the rate estimate vs. vibration rate for sinusoidal pulses presented to the fingertip. Different shapes represent different intensity levels used; notice that intensity has no significant effect on perceived rate.

Sherrick suggests that the present results support the belief that between three and five values of vibration rate can be distinguished by human subjects over the range of 2 to about 300 pps. This is a "worst case" situation in which no redundant dimension is present. When intensity is added to rate redundantly the number of recognizable rates increases from five to eight (Sherrick, 1985). Rovan and Hayward report that over a range from 70 to 800 Hertz, ranges broadly divided into 8 to 10 discrete steps are perceptible (2000). The number of distinguishable frequency bands observed on a given occasion is likely dependent on the experimental setup and procedure as well as the upper and lower bounds of the range used.

2.3.3 Intensity of vibration

By comparison to the auditory system which exhibits an impressive dynamic range of 120 dB, the vibrotactile sense is rather limited, with an intensity range of about 55dB above detection threshold, beyond which vibrations become very unpleasant or painful (Verrillo and Gescheider, 1992). In experiments involving vibrotactile stimulation, actuators are typically run at around 15 dB SL (where SL stands for *sensation level*, the level of the signal relative to the absolute threshold level for a particular subject). The region of intensities around this value represent what is often considered the comfort zone of vibration on the skin. When performing an audition-to-taction mapping, one

must take into consideration the disparate dynamic ranges of the two modalities. A number of psychophysical theories on cross-modality subjective intensity matching have been formulated and might be enlisted to this end.

2.3.4 Intensity Discrimination

Another important psychophysical measure is the ability to discriminate between two intensities. The smallest detectable intensity difference is often referred to as the *just noticeable diffference* (JND) in intensity. A range of values for the JND of intensity have been reported in the literature, the smallest JND (0.4 dB) reported by Knudson in 1928 and the highest (2.3 dB) by Sherrick in 1950. In a study by Gescheider *et al.* (1990), the best intensity discriminations were made when an intensity increment was imposed upon a continuous background 'pedestal' of vibration rather than on pedestals of brief duration. Because the methodologies and experimental conditions vary between labs, it is difficult to make direct comparisons of the results reported in these studies (Verrillo and Gescheider, 1992). In general, the haptic system is very sensitive to the amplitude of skin deformation, with a precision of less than 1 ? m and a range greater than 2mm (Pawluk, *et al.* 1998).

2.3.5 Subjective magnitude

When discussing matters of intensity and magnitude, it is important to distinguish between the *intensity* of a stimuli and its *subjective intensity* or *sensation magnitude*. Two sinusoidal waveforms of equal amplitude but different frequencies presented to the skin can result in unequal subjective intensities. In other words, one will feel more or less intense than the other even though they are of the same amplitude. Figure 2.4 depicts a set of contours of equal sensation magnitude plotted by Verrillo et. al. (1969). Each curve describes the combinations of frequency and intensity that result in judgments of equal subjective intensity. Verrillo and Gescheider point out that an important difference between these curves and equal loudness curves for hearing is that the hearing curves flatten as intensity increases (which tends to make high-intensity sounds appear equally loud regardless of frequency), whereas the vibration contours at various intensities are almost parallel. Because stimuli will presumably be presented at

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suprathreshold intensities, equal sensation magnitude curves must be taken into account when designing a vibrotactile stimulator (1992).



Figure 2.4. (Verrillo *et al.*, 1969) Equal sensation magnitude contours. Each curve describes the various combinations of frequency and intensity that give rise to equal sensation magnitudes.

Verrillo and Chamberlain (1972) determined the rate at which the subjective intensity of a signal grows as a function of amplitude of vibration. The curves shown in Figure 2.5 illustrate that the subjective magnitude of the stimulation increases as the physical intensity of the vibration is increased. Steeper curves indicate a more rapid increase in psychological magnitude. Note that the curves indicate that subjective magnitude grows more rapidly for body loci with lower sensitivity. These curves are important to consider when presenting a wide dynamic range of stimuli to multiple loci on the skin.



Figure 2.5. (Verrillo and Chamberlain, 1972) Subjective magnitude growth as a function of amplitude of vibration. filled circles = finger; x's = thenar; open circles = forearm.

2.3.6 Adaptation

When stimulated for relatively long periods, human sensory systems tend to adapt to stimuli; they readjust themselves to a new baseline. Prolonged tactile stimulation can result in what is known as *adaptation*, a decrease in the sensory magnitude or detection threshold of a stimulus. Verrillo and Gescheider note that its effects are more noticeable at threshold levels, but are manifest at suprathreshold levels as well. Sensation magnitude declines during the exposure to the adapting stimulus and then gradually recovers to the preadaptation level during the postadaptation period; recovery time ranges from a few seconds to several minutes depending on the duration and intensity of exposure (1992).

Kaczmarek *et al.* (1991) report that a 10-min stimulus 6dB over threshold raises the sensation threshold amplitude by 2dB, while a 40-dB stimulus raises the threshold by 20 dB. This adaptation occurs at least for frequencies from 10 to 250 Hz. Full recovery from adaptation occurs in approximately 2 min. Hahn (1973) reports that a 7 - 25 minute conditioning vibrotactile stimulus results in full adaptation i.e. the sensation threshold does not further increase at longer conditioning stimuli durations. Verillo and Gescheider

(1992) also note that conditions in which the skin is exposed to vibration containing a broad band of frequencies could result in a substantial amount of adaptation, since each of the vibrotactile channels may become adapted through exposure to stimulation within its own frequency range. The design of any tactile stimulator must account for the effects of adaptation.

2.3.7 Other stimuli parameters

Any display which engages a single mode of sensation within the tactile channel, i.e. vibration, is inherently limited in its stimulation capability. The technology for a tactile stimulator capable of producing the full range of tactile sensations is currently under development. Designers of tactile stimulators often face the task of creating as rich and expansive a set of stimuli as possible given the limitations of working with only one tactile sensation. In the context of tactile displays designed with the transmission of discrete information in mind, the set of stimuli will likely depend on the amount and type of information being presented. In the context of the research presented in this paper, the versatility of a tactile composition system increases as the set of stimuli grows. In addition to the dimensions of frequency and intensity, the waveform or spectral content of a tactile stimulus can be modulated to yield even more variation in the stimulus set. Rovan and Hayward explain that the gamut from pure sine tone to frequency rich spectrum to noise is characterized as a continuous transition from smoothness to roughness (2000).

The sensation experienced by any sensory stimulus is also affected by the duration of the stimulus. The duration of a stimulus is usually inversely proportional to the minimum intensity needed to perceive it. Stimulus duration is an important component of word recognition by the auditory system and hence will be a particularly important consideration for the development of auditory substitution devices (Verrillo and Gescheider, 1992).

2.3.8 Subect Variables

One interesting inter-subject variable is that sensitivity is a function of gender. The results of experiments indicate that because sensation magnitude grows more rapidly in women than in men, the perceived sensation of suprathreshold stimuli is greater for women (Verrillo, 1979). Verrillo and Gescheider also explain that a female's sensitivity varies over the duration of the menstrual cycle (1992).

2.4 Spatio-temporal patterns on the skin

It is common for tactile stimulators to use multiple channels, spatially distributed in some manner on the skin. In fact the system presented herein constitutes a multi-channel tactile stimulator. The following sections discuss some of the psychophysics associated with temporally and spatially varying groups of stimuli presented to the skin. While our sense of touch is very powerful with respect to its parallel processing capabilities, the ability of a person to perceive patterns of stimuli - and consequently the effectiveness of a tactile stimulator - is limited by the thresholds and attention mechanisms discussed below.

2.4.1 Amplitude modulation

In some vibrotactile displays, the envelope of some carrier waveform is modulated. Weisenberger (1986) modulated sinusoidal carrier frequencies within the range of human sensitivity as well as wide band and narrow band noise carriers. The results show that the perception of amplitude modulation using sinusoids is superior to that with wide or narrow band noise. Maximal sensitivity occurred at modulation frequencies of 20-40 Hz. Weisenberg concluded that, although not as sensitive to amplitude modulation as the auditory system, the vibrotactile system can reasonably be expected to resolve temporally varying waveforms that can be utilized for processing speech information by the skin. In music, amplitude modulation is used to create an effect called *vibrato*. By modulating the amplitude of vibrotactile signals, a tactile equivalent of vibrato might be achieved.

2.4.2 Gap detection

Gescheider (1967) measured the minimum detectable separation between a pair of tactile clicks as a function of click intensity and found that gap detection improves as a function of the timer interval separating the clicks and the intensity of the clicks. Gap detection thresholds were found to be about 10 ms, but may be as low as 5 ms for highly damped mechanical pulses. Studies regarding the detection of gaps between sinusoidal bursts showed that the gap became easier to detect as its duration increased, and gaps between sinusoidal bursts were significantly easier to detect than those between bursts of noise. Subjects reported that the sinusoids felt 'smooth' and perceived the gap as a small slick in the stimulus; the noise, however, felt 'rough' and the gap was perceived as a modulation of stimulus amplitude (Verrillo and Gescheider, 1992). Temporal gaps in tactile stimuli may be applied in a controlled manner to create a variety of interesting effects.

2.4.3 Temporal order

When a sequence of tactile stimuli is presented to spatially distributed sites on the body, our ability to determine the order of presentation is a function of the rate of presentation. Hirsch and Sherrick (1961) found the threshold for temporal order judgments to be about 20 ms between the onsets of two brief stimuli. This threshold, however, was found to increase progressively as the number of stimuli increased beyond two (Sherrick, 1982). When the number of stimulus elements is increased to five or six, the stimulus onset intervals needed for correct identification of the temporal sequence may be nearly 500 ms. Verrillo and Gescheider (1992) explain that a tactile communication system which requires absolute identification of the temporal order of several sequentially presented stimuli presented to different body sites would require very slow rates of presentation information if it is to be effectively used; too slow for the perception of speech in real time. This threshold places limits on the bandwidth of any tactile stimulator that presents information both spatially and temporally to multiple body sites. Issues pertaining to temporal order thresholds are addressed in later sections of this paper.

2.4.4 Spatial Resolution

Kaczmarek *et al.* asserts that spatial resolution is not a uniquely defined quantity, but depends on the particular type of stimulus and task to be performed. Temporal and intensive cues also provide spatial information at the perceptual level (1991). Spatial resolution is proportional to the spacing between mechanoreceptors in the skin. Thus the highest spatial resolution is found on the fingerpad and is approximately 1.0 mm (Phillips and Johnson, 1981). With a sensitive enough procedure (eg two-alternative forced-choice procedures), it is always possible for observers to discriminate a spatially separated pair of touches to the skin (even if simultaneous) from either a single touch or even a pair opposed to one another (Kaczmarek *et al.*, 1991).

2.4.5 Effects of multiple stimulation

Below is a list, taken from Verrillo and Gescheider (1992), of the perceptual phenomena arising from the application of multiple stimuli to different body sites. In a tactile stimulator - such as the one presented in this paper - which makes use of temporally and spatially distributed patterns of stimuli, these phenomena become very pertinent. These phenomena will likely affect decisions made in the tactile composition process and are addressed in subsequent sections of this paper.

Masking

Masking is the reduced ability to detect a stimulus in the presence of a background, or masking stimulus. In case of simultaneous masking, the signal and masker are presented simultaneously. With forward and backward masking, the masker comes respectively before and after the signal. When the masker is placed in the high frequency region (275 Hz) and the signal at low frequencies (15, 50, 80 Hz), there is a plateau in the masking function (threshold shift of signal vs masker intensity) indicating a cessation in the masking increment. This phenomenon occurs when masker and signal excite different mechanoreceptor systems located in the skin. Within certain intensity limits, the presence of high frequencies does not affect the detection of low frequencies and vice versa. The effective operation of the system presented herein hinges on this last point.

Enhancement

Enhancement occurs when the presence of a brief stimulus causes a second stimulus to appear to be of greater intensity than when it is presented alone. Measurements taken by Verrillo and Gescheider (1975) demonstrate that enhancement occurs when the two stimuli are within 500 ms of each other and that the effect is a decreasing function of the inter-stimulus time interval. Enhancement is evoked at both high and low frequencies (300 and 25 Hz), but disappears when high and low frequencies are mixed in the same stimulus presentation.

Summation

Summation refers to the total or combined sensation magnitude of two stimuli occurring close together in time. Summation is more robust when the frequencies are more widely spaced, and is the opposite of the enhancement effect.

Suppression

Suppression occurs when the presence of one stimulus decreases the ability of the subject to detect a second stimulus when the two stimuli are delivered to different places on the surface of the skin. One may think of suppression as masking from a remote site.

2.5 Tactile Illusions

Sensory illusions arise when some set of conditions forces a sensory system to misinterpret the stimuli being presented to it. O'Modhrain points out that one of the first sensory illusions investigated by Weber, the father of modern psychology, involved the haptic senses (2000). As we will see, tactile illusions will form the basis of several compositional building blocks for tactile composition.

Helson and King (1931) demonstrated the *Tau effect*, in which perceived distance between two tactile sensations is positively related to the temporal interval between stimulation of the two sites. Another interesting illusion was discovered in the course of experiments on tactile sound localization. Gescheider (1965) amplified the outputs of two spatially separated microphones and fed them into two tactile stimulators placed on different fingers of the same hand. Subjects were asked to localize different sound sources using only the tactile cues provided by the setup. The results demonstrated that the accuracy of localization was nearly the same for the skin as for the ears. The really interesting phenomenon arose in later sessions of the experiment, when many observers reported that tactile sensations were projected out into space between the two fingertips to a position corresponding to the sound source (Verrillo and Gescheider, 1992).

When two spatially separated points on the skin are stimulated with certain timings, the result is apparent motion on the skin. Specifically, when the time interval between tactile stimuli applied to spatially separated sites is 75-150 ms, the sensation is perceived as moving rapidly from the first to the second test site (Verrillo and Gescheider, 1992). The dependence of inter-stimulus interval (ISI) on duration for optimal apparent motion has been found to be virtually identical for visual, vibrotactile, and electrocutaneous stimuli (Sherrick and Rogers, 1966). In 1972, Geldard and Sherrick discovered a new type of illusion of apparent motion which they coined the *cutaneous rabbit* (which later came to be known as *sensory saltation*). They found that when a train of taps was presented to two distal points on the skin, the resulting sensation was a smooth progression of jumps up the arm, as if a tiny rabbit were hopping from wrist to elbow. Geldard and Sherrick found that the time between taps is not very critical; good, well-spaced hopping occurs over a wide range of ISI values from about 25 - 200 ms. With the timing of the pulse train held constant, reducing the number of taps at each locus (N) causes the hops get longer; increasing N makes the hops shorter. In addition, hopping has been observed when two contactors are as close together as 2 cm and as far apart as 35 cm (Geldard and Sherrick, 1972). The neural basis for saltation is still under investigation. The phenomenon of apparent motion on the skin has great potential for use in tactile navigation systems; several efforts are currently underway. As one can imagine, the possibilities for apparent motion as a compositional device are endless.

3 Relevant research

The field of tactile composition is truly multidisciplinary. It is important, at the first stirrings of a developing field, to maintain an open mind and not constrict thinking to one paradigm or area of study. The following section is intended to be an overview of some relevant research in haptics as well as non-haptics fields. It is in part an attempt at identifying the range of disciplines that can potentially contribute to the development of tactile composition. Previous research that provides evidence for the feasibility of tactile composition is also presented below.

3.1 Taxonomy of Haptics Research

The line of research undertaken in this paper is relatively young. Hence it seems useful to place it in the general scheme of haptics research. The following taxonomy of haptics research is adapted from the Haptics Community Webpage⁵.

Mechanical design

The design of haptic and tactile devices is rooted in multiple disciplines. Our sense of touch is inherently mechanical and so this is a vital area of haptics research. Designing the mechanical systems for a force-feedback exo-skeleton or a high-resolution matrix of pins is no trivial problem. A common challenge faced in this area is that of limiting the size of a device; in particular there is often a tradeoff between versatility and portability.

Control issues

Any mechanical device requires a means of control. Hence systems control is an essential dimension of the design process. This area of haptics research deals with the design of effective algorithms and methods for controlling haptic devices and tactile stimulators.

Simulation design

The addition of a haptic component can dramatically increase the "realness" of virtually simulated environments. Much of the research in this area is concerned with the design

⁵ http://haptic.mech.northwestern.edu/intro/

of force-feedback devices which allow a user to probe a virtual environment or object, the goal being to realistically reproduce such features as surface texture, object shape, and compliance. There has been a strong interest in augmenting virtual reality technology with haptic feedback.

Psychophysics

Psychophysics is a field of experimental psychology that uses specific behavioral methods to determine the relationship between the physical world and people's subjective experience of that world. Psychophysicists conduct scientific experiments that are carefully designed to let them figure out which physical parameters actually determine a subjective perceptual dimension.⁶ Much of our understanding of the haptic system comes from psychophysics research and it is invaluable for informing the design of haptic and tactile devices.

Tactile Stimulator

As described in the previous section, the skin can receive a variety of physical stimuli including vibrations, small-scale shape or pressure distribution, and thermal variations. This area of haptics research aims to design devices which can realistically generate these sensations on the skin. Current technology is not advanced enough to construct a singular device capable of generating all of these sensations. Hence current efforts tend to be focused on the design of devices which engage a specific tactile response i.e. vibrotactile stimulator for vibration, matrix of pins for pressure, thermal display for temperature, etc.

⁶ Susan J. Lederman, *Introduction to Haptic Display: Psychophysics*, Haptics Community Webpage http://haptic.mech.northwestern.edu/intro/psychophysics/

*Teleoperation*⁷

Teleoperation is the remote control of robot manipulators. Perhaps the most common application of this technique is in construction equipment such as excavators in which the operator controls the velocity of the joints of the "robot" to accomplish the task. However, most construction equipment does not provide force feedback directly to the hand. When the user is located farther from the remote robot, considerable engineering effort must be applied to reproduce the sensory feedback information which allows accurate and efficient control. Haptic feedback devices were pioneered in teleoperation systems as far back as the 1940's. The use of teleoperation in surgical procedures as well as deep sea (and space) exploration vehicles is also currently under investigation.

Sensory substitution systems

This field might be included under tactile stimulators, but has received enough attention to warrant its own category. Sensory substitution systems provide their users with environmental information through a human sensory channel (eye, ear, or skin) different from that normally used, or with the information processed in some useful way. This class of systems includes tactile vision substitution, tactile auditory substitution, and teletouch (Kaczmarek et.al., 1991). This area of research is often concerned with the information processing capabilities of the skin and deals with the design of tactile aids for the visually and hearing impaired.

Where does this paper fit in? One might categorize the present research as a form of *tactile art*. As we will see, however, tactile art encompasses a wide spectrum of work ranging from "environmental sculptures" to texture-based art for the visually impaired and even "simulated copulation capsules"! The term *tactile composition* seems best suited to describe the core ideas expressed in this paper. We might say that tactile composition, as an emerging field, is interested in the ways in which our sense of touch

⁴ Blake Hannaford, *Introduction to Haptic Display: Teleoperation*, Haptics Community Webpage http://haptic.mech.northwestern.edu/intro/teleoperation/

can be harnessed as a sensory channel capable of understanding artistic expression as well as with the design of tools which will facilitate compositional activities for the skin.

The ultimate goal of the author is to establish an art form for the sense of touch analogous to the way music is for the ear. To an extent, this line of research represents a bridge between the artistically rooted world of tactile art and the more "practical", technologically driven world of haptics research. As opposed to the areas of haptics research described above which concern themselves primarily with the realistic recreation of tactile and proprioceptive/kinesthetic stimuli (in the case of simulation design) or the transmission of information (in the case of sensory substitution systems and teleoperation applications), this paper views haptics from an aesthetic perspective. In other words, it represents a general shift in focus toward more abstract and expressive applications of haptics technology.

3.2 Research on the tactile communication of speech

A considerable amount of research has been done on sensory substitution systems; particularly in the area of tactile aids for the visually and hearing impaired. While a variety of fascinating devices have been designed to these ends, this section will focus on the area of tactile speech communication due to its special relevance to tactile composition. At the core of tactile speech communication is a transformation across sensory modalities from audition to touch. This basic idea is also at the heart of tactile composition. This commonality makes tactile speech communication research a logical place to begin thinking about tactile composition; in fact for the author, it was the starting point for his investigation of the field of haptics. In addition to providing evidence for the feasibility of tactile composition, the body of research in this area provides invaluable insights into the interactions of audition and touch.

A number of natural methods which use the sense of touch to convey speech have been developed. One such method is called *the Tadoma method* and involves the placement of the hands over the face and neck of the talker in order to monitor the actions present on the face during articulation (Reed et.al., 1992). Reed et.al. explains that these natural methods are important to the history of tactual speech communication because they

provide evidence that the tactual sense has the capacity to serve as an effective channel of communication as well as important background information for the development of artificial tactile devices (1992).

In the earliest studies of artificial tactile devices, RH. Gault and colleagues applied raw acoustic input directly to the skin through a hollow tube, and later through an earphone driver held in the hand (Reed et.al., 1992). Reed et.al. note that a major advancement in the field was made with the application of *vocoding* techniques in the 1940s. This new class of devices relied on the principle of *frequency-to-place transformation*, in which the location of stimulation on the skin corresponds to a given acoustic frequency region. In addition to frequency cues, these devices provided information about intensive and/or temporal properties of the acoustic signal (1992). Table 3.1 (Reed et.al., 1992) is included to give an overall sense of the stimuli parameters employed by several devices in this class.

Display/Researchers	#Frequency Bands	Locus	Stimulus Waveform	Transducer
STL Tactual Vocoder (Lövgren & Nykvist, 1959) (Pickett & Pickett, 1953)	10	Fingertips	Amp-Mod 300-Hz Tones	Bone Conduction Vibrators
Tactus (Kringlebotn, 1968)	5	Fingertips	Pulse Train	Bone Conduction Vibrators
Ifukube & Yoshimoto (1974)	16 (16x3 array)	Finger	Amp-Mod 200-Hz Sq. Waves	Solenoid Vibrators
Queen's University Vocoder (Brooks, Frost, Mason, 1985)	16	Forearm	Amp-Mod 100-Hz Tone	Solenoid Vibrators
Cochlear Model (Keidel, Biber, 1961)		Forearm	Traveling Waves	Mechanica!
MESA (Sparks, et al., 1978)	36 (36х8 алтау)	Abdomen	Biphasic Pulses	Electrodes
Tacticon (Saunders, 1978)	20	Abdomen	Biphasic Pulses	Electrodes

Table 3.1. Examples of several spectral displays varying in the number of frequency bands used, body locus, stimulus waveform, and transducer type.

Reed *et al.* explain that evaluations of tactile vocoders used in conjunction with lipreading have produced results that are somewhat realistic in meeting the demands of everyday communication. The authors present evidence which suggests that the type of

training – laboratory versus field – and amount of training given to users of artificial tactile devices is crucial in predicting performance results. They conclude that further research is needed to acquire quantitative results on the performance of experienced users of tactile devices (1992). The results of performance studies with tactile aids may one day be relevant to the study of the learning and memory processes associated with tactile composition. In any case, evaluations of existing tactile aids is important to consider when thinking about the practical aspects of using tactile stimulators.

3.3 Some key studies

Much of the research presented in the present chapter lends some weight in answering the fundamental question: *Will tactile composition work?* The following studies in particular provide experimental evidence in support of an affirmative answer to this question.

3.3.1 Saltation and apparent movement studies

Upon learning about the phenomenon of sensory saltation, the author's immediate thought was: Can it be harnessed and used in a real application? And if so, how? A study by Tan *et al.* (2000) provides some encouraging results. The study was designed to test the hypothesis that saltatory signals can be readily perceived without training. Using a 3x3 tactor array, "saltatory lines" were generated in different directions against the back of the subject, who was subsequently instructed to draw out the perceived paths. The results showed that the saltatory signals used in the study shared unique and consistent interpretations among the group of subjects tested. These results demonstrate people's ability to discern saltatory patterns and lend much weight to the possibility of applying sensory saltation in a system for tactile composition. Efforts are underway to develop a general-purpose haptic display based on sensory saltation that can find application in many areas including a haptic driving navigation guidance system (Tan *et al.*, 2000).

Tactile composition is ultimately concerned with the way tactile stimuli feel. Hence qualitative reports of tactile sensations are especially invaluable for tactile composition *in practice*. Tactile sensations can only be truly apprehended through first-hand experience

- one can have some sense of a piece of music after reading a review, but only upon hearing it can one fully understand and appreciate it. In any case, the following accounts by various experimental subjects illustrate the vividness of and compositional potential for apparent motion phenomena. In one study of apparent movement, one subject described the sensation as a powerful vibratory "gouging" that moved from one stimulus site to the other at a rate depending on the distance between sites and the time between onsets. At its best, the feeling was equivalent to that produced by actually moving a vibrating object smoothly along the thigh (Sherrick and Rogers, 1966). In another experiment on saltation, it was possible to induce a vivid hopping that traveled up one arm, across the neck, and down the other arm by the use of five contactors, two widely separated on each arm and one on the nape of the neck (Geldard and Sherrick, 1972). When Bice applied six successively energized vibrators around the thorax of a subject, the result was a vivid movement that might be labeled "haptokinetic" because it gave the impression that he was at the focus of intense rotary motion (Sherrick and Rogers, 1966). The author can attest, based on his personal experience with saltation, that the sensation of apparent motion on the skin is surprisingly dramatic and perceptually powerful.

3.3.2 Tactile communication studies

If it is to keep the feeler's interest, a tactile composition will probably need to exhibit some degree of complexity⁸. Even some of the simplest musical compositions involve relatively complex temporal, frequency, and dynamic variations. The auditory system has evolved a number of exquisite mechanisms, which allow a listener to resolve and process this complexity. But what about the skin? Is the human haptic system capable of resolving and understanding the potentially complex, rapidly varying temporal and spatial patterns presented to the skin in the course of a tactile composition? It turns out that several studies have been done, aimed at determining the skin's ability to receive and understand complex systems of symbols.

Geldard (1966a) describes an experimental language for tactile communication called Vibratese. Vibratese was comprised of 45 separate signals; three intensities, and three

⁸ David Durlach, personal communication 11.02.00

durations were delivered to five different spots on the chest. Letters of the alphabet were each assigned a signal representing a unique combination of duration, intensity, and location $(3 \times 3 \times 5 = 45)$. The Vibratese alphabet was mastered by subjects in mere hours. The training sessions were discontinued not because the learning limit had been reached, but because the equipment used in the setup could go no faster – one subject was receiving at a rate about twice that of proficient Morse Code reception! The successful outcome of the Vibratese study illustrates the skin's astounding ability to cope with complexity. Another attempt at tactile communication was the *Optohapt* (Geldard, 1966b), which converted typed characters into tactual signals having various spatial and temporal properties. This device used transducers situated at nine widely scattered loci on the body. As we will see, the distributed situation of transducers in this device makes it very similar to the Skinscape system presented in Chapter Four. A systematic investigation of the similarities of different symbols used in the Optohapt system led to some valuable insights about the discriminability of tactile patterns, some of which are addressed in subsequent chapters of this paper.

3.4 Visual music

Similar to tactile composition, *visual music* encompasses the idea of *cross-modal composition* (where 'modal' refers to sensory modality, not to be confused with *modes* as used in a musical context), combining the mediums of sound and sight. A consideration of the visual music field reveals a number of issues overlapping with tactile composition. While many of these issues are of a technical nature and can inform the corresponding technical aspects of tactile composition, of equal importance is the creative inspiration and direction that this field can provide for the budding field of tactile composition. We will leave a detailed investigation of such issues for future study, however. This section is intended to give a brief overview of the field and highlight its general relevance to tactile composition.

The cross-modal art form known as visual music has a history dating back to the late 18th century when the first color organ, a stringed musical instrument combined with moving transparent and colored tapes, was constructed. Cytowic sketches a nineteenth-century

art movement, comprised primarily by inventors of color organs, that sought sensory fusion. Interestingly, the most elaborate experiments with sensory fusion of color and music were carried out by inventors, not by artists. After the first design of the 'clavecinoculaire' by the eighteenth century French Jesuit Castel, the nineteenth century showed a large number of attempts to develop a device that could produce music and color simultaneously on the basis of tone-color correspondence schemes (1995).

The tradition of visual music has been carried on into the 20th century, coming a long way since the early days of color organs. Pellegrino writes that multimedia, intermedia, or mixed media performances occurred with increasing frequency from the mid-1960s to the mid-1970s. Composers, engineers, performers, choreographers, filmmakers, theatrical people, and light artists collaborated to produce colorful and exciting public events. The collaborations resulted in perspective exchanges, cross-fertilizations that inspired artists of a particular specialty to explore related fields, and, in some cases, to attempt to integrate essential aspects of those fields into higher-level art and sound forms (1983). The modern laser light show – in which choreographed visual sequences are projected via lasers onto the dome-like screen of a planetarium – has become a recreational institution among recent generations. Live video mixing as well as the music video are additional examples of cross-modal composition. These days it is increasingly common to encounter real-time choreographed video performances at electronic dance music events (also known as raves). Plugins for software media players such as Winamp, which produce elaborate abstract animations synchronized with music, have become very popular among computer users in recent years. A number of software tools for composing visual music are also commercially available. Two examples are Imaja's *Bliss Paint* and Notting Hill's *Dancer DNA*. These programs allow complex sequences of image synthesis events to be triggered on the fly by audio and/or MIDI input.

3.5 Tactile feedback for musicians

Sound and touch have a relationship that dates back to the origins of music. In the traditional closed loop between performer and instrument, intention gives rise to gesture, gesture gives rise to sound, and feedback – including visual, aural, and haptic/tactile

information – is used to gauge the result. Kinesthesia and touch are a part of performance, from the buzz of the reed to the bruise of the chin rest (Rovan and Hayward, 2000). Cues received in the form of tactile feedback are vital for effectively playing most musical instruments. An interesting study by Rovan and Hayward (2000) uses a vibrotactile stimulator to create artificial tactile feedback for use with a gesturedriven, open-air electronic music controller⁹. The results showed that significant perceptual advantages were derived with the addition of tactile feedback to the open-air controller. Tactile feedback from musical instruments is an example of a preexisting interaction between music and our sense of touch that is often taken for granted. While not directly relevant to tactile composition, studies in this area may provide insight into our perception of tactile stimuli in a musical context.

3.6 The art world

Although nowhere near as much as its visual and auditory counterparts, the sense of touch has received some attention in the art world. We will look at a handful of pieces to get some sense of previous explorations into the use of touch as a sensory channel for artistic expression. In 1942 the Museum of Modern Art in New York exhibited for the first time a new type of sculpture called *handies* or hand sculpture. They consisted of small, smoothly rounded pieces of polished wood in abstract shapes that would fit comfortably into the human hand and could be squeezed and turned this way and that to vary the tactile sensation. The artist who created them stressed that they were meant to be felt rather than looked at, and suggested that they would make an excellent substitute for cigarettes, chewing gum or doodling for those people who tend to be fidgety in committee meetings (Morris, 1971).

In the 1960s, certain artists attempted more ambitious assaults on the bodies of art-lovers by creating 'environmental sculptures'. These have taken many forms, some of which have included a kind of play-space into which the visitor walks, there to be assailed by a series of varying tactile impressions as he passes through tubes, tunnels and passageways,

⁹ Open-air controllers are gesture-driven electronic music interfaces which unchain the performer from the physical constraints of holding, touching, and manipulating an instrument. They often use non-contact sensing technologies such as near-field capacitive measurement, infrared, ultrasound, video, etc. (Rovan and Hayward, 2000).
walled and hung with a wide variety of textures and substances (Morris, 1971). The *Tactile Dome* located at the Exploratorium in San Francisco's Palace of Fine Arts has been open since 1971. The exhibit is encased in a geodesic dome about the size of a large weather balloon. Visitors enter through a light-lock room into a totally dark maze. Then, for an hour and fifteen minutes, they feel, bump, slide and crawl through and past hundreds of materials and shapes which blend, change and contrast. Seemingly the tactile equivalent of a light show, the tour is actually a carefully planned and structured succession of shapes, temperatures and textures which require the full range of the touch sense to perceive. The creator's idea was to make people aware of what a complex, sensitive and underused sense touch is, and to train them to use the astonishing range of its perceptions¹⁰.

A more recent piece of a very different flavor is the *Ping Body* project headed by an artist called Stelarc. This project involved the use of a muscle stimulation device which controlled the proprioception and musculature of the artist's body based on Internet activity¹¹. The present paper is concerned with composition for the tactile sense (as defined in Chapter One). The Ping Body project raises the interesting possibility that the activity of composition might one day be expanded to the proprioceptive / kinesthetic channels. The idea of "being moved" by a composition would assume a whole new meaning!

In addition to being exploited by sensory substitution systems, the sense of touch has also been harnessed as a vehicle for conveying art to the visually impaired community. An exhibit titled *Please Touch* at Simon Fraser University in Canada, consisted of artwork that employed *tactile color*, a method of color-coding using textured surfaces, which correspond to different colors. A growing number of artists and teachers are interested in the area of sensory art and its implications for the visually impaired community as well as for children with various disabilities.

¹⁰ Description adapted from original 1971 San Fransisco Exploratorium Tactile Dome press release.

¹¹For more information, see Stelarc website: http://www.stelarc.va.com.au/pingbody/index.html

4 Skinscape system Design

4.1 System specification

A system which facilitates tactile composition was designed and implemented. The system consists of both hardware and software components which are described in detail below. The three main parts of the system are the vibrotactile stimulator, the control system for the stimulator, and the composition environment. Before going into the details of the design, we will consider a typical usage scenario for the system. A composer¹² would first put on the vibrotactile stimulator, which provides tactile feedback during the composition process. Basically, the stimulator consists of a set of vibrating transducers attached to the surface of the body at different loci. Next, the composer would open up a pre-composed audio file within the composition environment – whether in the form of music or spoken narrative – and proceed to compose a synchronized tactile component. We will talk more shortly about what exactly is entailed by the act of composition. Once the composition is recorded and saved, it can be played back at any time and experienced by anyone wearing the stimulator. The term *observer*, analogous to a listener of music, will be used herein to refer to the person wearing the stimulator who passively experiences a tactile composition. What follows is a breakdown of the system components as well as a description of the associated design processes. Figure 4.1 is a block diagram of the main components of the system. A photograph of the system is also shown below in Figure 4.2.

¹² Note that the term *composer* will herein be used to refer to the person using the composition environment to create a tactile composition.



Figure 4.1. Block diagram of Skinscape system.



Figure 4.2. Photograph of Skinscape system being used by the author. (a) V1220 transducer located on wrist; (b) Velcro adjustable elastic band; (c) Interactor cushion amplifier unit; (d) 12-channel V1220 amplifier unit; (e) Digi001 hardware interface; (f) ATX-M3H headphones; (g) Macintosh G4; (h) screenshot of ProTools LE audio editing environment.

4.2 Vibrotactile stimulator

As explained in Chapter One, a tactile stimulator is a device which generates tactile sensations against the skin of its user. There are different kinds of stimulators, each of which typically engages one specific tactile response i.e. pressure, slip, vibration, temperature. Several classes of stimulator were considered before arriving at the one used in the final design. The first type to be considered was an array of closely-spaced pins that can be individually raised and lowered. This type of stimulator simulates smallscale shape or pressure distribution. The idea behind using this device for presenting a tactile composition was that a matrix of pins could display patterns to the hand with relatively high resolution, similar to the way a computer monitor displays animated images to the eye. However, these devices are particularly difficult to design and control due to the requirement to fit large numbers of fast and powerful actuators in a very small space; thus there is often a tradeoff between portability and performance (Pawluk et al., 1998). In addition, these devices tend to take advantage of the high spatial resolution on the hand and consequently have a small area of stimulation such as the fingerpad.

Another type of stimulator takes advantage of the skin's ability to detect changes in temperature. *Thermal displays* are usually based on Peltier thermoelectric coolers. These thermoelectric devices usually come in the form of a small tile that uses an applied voltage to 'pump' current from one side to the other, increasing the temperature of one side while decreasing the temperature of the other. The response of these devices to their inputs are too sluggish to make them practical for use in a tactile composition system. The bandwidth of the skin's response to temperature changes is also relatively low. The possibility that thermal properties could one day be used to create slowly varying patterns in a tactile compositions was not neglected. With the present limitations of most tactile stimulators to a single tactile response, however, this idea is not yet realizable.

A multi-channel vibrotactile stimulator was chosen for the final design. This decision was based on several factors. First, a vibrotactile stimulator would be the easiest to design, implement, and work with. A number of vibrational transducers are commercially available. In general there is also significantly less overhead with regard to the mechanical aspects of designing a vibrotactile stimulator. Devising a control scheme for such a device, for example, would prove much easier than say, for a pin-matrix. Basically, all that is needed is a set of oscillators and some fairly simple control systems. This problem is especially simplified given the availability of software and hardware tools for digital audio processing. Second, a surprisingly rich and expansive set of tactile effects can be yielded, given the simplicity of the stimulation device. Chapter Five considers how the vibrotactile stimuli dimensions of waveform, intensity, frequency, envelope, and duration can be used as building blocks for composition. Third, the psychophysical variables of vibrotactile perception generally fall within ranges which make them compatible with speech and music; after all, sound is simply the vibration of air. Accordingly, the development of tactile composition will benefit from the strong analogies that can be drawn with the auditory stimuli comprising music.

4.2.1 Vibrotactile Transducers

A number of factors are important to consider in designing, and in this case simply choosing, a transducer. One is contactor size. Verrillo (1966) obtained the following results from both glabrous skin on the hand and hairy skin on the forearm. When very small contactors are used the threshold response level is independent of frequency. At higher frequencies (80-320 Hz), sensitivity increases directly with the size of the vibrating surface, at the rate of approximately 3 dB per doubling of contactor area. However, at low frequencies (40 Hz and below), the size of the contactor has no effect on the detection threshold. Contactor size will also influence the perception of suprathreshold stimuli. Spatial summation is observed at suprathreshold levels of stimulation and the magnitude of sensation has been shown to increase as contactor size increases (Verrillo and Gescheider, 1992). Other factors include percentage of time the contactor touches the skin, method of control, and comfort.

Pager motors were considered, but ruled out due to their limited frequency range; most pager motors can simply be turned on and off and vibrate at a single frequency. The V1220 transducer, illustrated in Figure 4.3, manufactured by Audiolo gical Engineering¹³ was chosen for the final design. These transducers are used in a commercial line of tactile hearing aids. As shown in Figure 4.3(b), the device consists of a magnet mounted on a small cantilever driven by a solenoid enclosed in a 2 x 3 x 1 cm. plastic casing. The frequency response peaks at 250 Hz – the frequency of vibration to which the skin is most sensitive - and is plotted in Figure 4.4. The contact area is slightly less than 4 cm². These transducers are extremely versatile, capable of delivering powerful vibrations with

¹³ Audiological Engineering is a manufacturer of tactile aids for the hearing impaired.

a wide range of frequencies and waveforms to a relatively isolated area on the skin.



Figure 4.3. (a) Photograph of a V1220 transducer. (b) Schematic of the internal mechanism of a V1220 (Chole wiak and Wollowitz, 1992).



Figure 4.4. Frequency response of V1220 transducer (Audiological Engineering).

Somewhere along the design process, the perceptual importance of low-frequency vibrations to tactile composition was realized. The frequency range of the auditory system extends all the way down to 20 Hz. It was hypothesized that much perceptual and compositional value could be added to the system with the provision of an equivalent tactile low-end. Anyone who has experienced a rumble in their stomach at a concert, club, or even a parade with marching bands, can probably attest to the power of low-frequency vibrations; especially in conjunction with another medium such as music or movies. Accordingly, the *Interactor Cushion* manufactured by Aura Systems, Inc.,

which imparts low-frequency vibrations to the back, was added to the system. This device is intended for use with both video games and music listening (See Appendix _______ for a more detailed description of this and other similar devices) and basically consists of a low-frequency audio woofer enclosed in a cushion. The vest version of the Interactor was also tested. Although it was capable of imparting more intense stimuli to the back of the wearer, its hard plastic enclosure made it too uncomfortable for extended periods of use. In addition, there was significant vibrational leakage into the shoulder bones through the straps of the vest, whereas the cushion version is situated further down the back, giving it better isolation from the high frequency transducers on the arms.

4.2.2 Transducer loci

For reasons such as wearability and portability, many tactile stimulator designs apply dense arrays of actuators to a small patch of skin, say on the palm of the hand or a fingerpad. It seemed more intuitive for tactile composition to utilize the entire organ of skin as the receiver, resulting in an overall greater feeling of tactile immersion. An analogy can be drawn here with the field of dance, which similarly operates on the fundament al idea of an interpretation of sound through motion. Although a dancer might incorporate complex manipulations of the fingers into a performance, the compositional tool is the body in its entirety. Analogously, for tactile composition, the skin can be viewed as an expansive tactile canvas on which compositions unfold.

Accordingly, the configuration shown in Figure 4.5 was arrived at. The digital to analog (D/A) converter used in the system was limited to 8 channels. Given this constraint, it was decided to situate the transducers along the length of the arms. The hardware is expandable though, so a future version of the system might incorporate vibrators located on the legs and torso. The insides of the wrists and elbows were chosen based on the psychophysics of glabrous (non-hairy) skin; it is generally more sensitive than hairy skin. The wrists, in particular, were chosen for two reasons: (1) the sensitivity of the skin on the wrist is more compatible with that at the elbow and shoulder as opposed to the extremely sensitive skin on the palms and (2) with the transducers on the wrists, the hands are freed for the compositional activities entailed by the system, which require use

of both the keyboard and mouse. The placement of transducers on the creases of the elbows partly serves to bridge the perceptual roadblock represented by joints for sensory saltation.



Figure 4.5. Transducer situation on body. The low-frequency transducer sits against the lower back of a chair.

The lower back was chosen as the receiving site for the low-frequency vibrations. First of all, although there is reasonable spatial resolution on the chest and back – as demonstrated, for example, by Tan's saltation study (see Section 3.3.1) – these areas are generally bony and have lower sensitivity than the arms. This is illustrated by the sensory humunculus diagram shown in Figure 2.1. Second, the gut and roughly, the lower torso are the regions of the body in which we tend to experience those high intensity, low-frequency vibrations induced by certain kinds of music. This probably has something to do with the resonant frequencies of organs located in this region of the body. Finally, the back was chosen over the stomach for reasons of wearability and comfortability.

Another important factor to consider is vibrational leakage. Cross-talk between transducers could result in a number of potentially undesirable effects including excessive adaptation, masking, and suppression. The head in particular is a problematic region for vibrotactile stimuli with regard to vibrational leakage. Vibrations delivered to the head have a tendency to propagate through the skull and into the middle ear, causing the vibrations not only to be felt, but also heard. This auditory artifact is especially undesirable for a tactile composition system in which the audio and tactile components must be well isolated. Correspondingly, the situation of transducers in the region around the head was avoided. Bekesy noted that the propagation of traveling waves on the skin decreases with increasing frequency (1955). The situation of the low-frequency transducer on the lower back provides a considerable amount of isolation from the high frequency transducers on the arms.

4.2.3 Transducer mounting

An important specification for the mounting design was comfort. Specifically, it was desirable to minimize the presence of the transducer on the skin of the wearer in its static state, i.e. when receiving no input. A structure (such as that used experimentally by Sherrick and Rogers, 1966) which suspended the vibrators so that they just touched the skin, might solve this problem, but would be unnecessarily complicated and highly impractical for the present application. A simple strategy using adjustable elastic Velcro straps was devised. As illustrated in Figure 4.2, the transducer is clipped to the elastic band and directly contacts the skin. This method of mounting is somewhat awkward; however, time constraints did not allow for a more comfortable design. Future designs should include some soft material between the transducer and the skin for increased comfortability. In addition, the transducers might be mounted inside of a continuous elastic sleeve which the user can easily slide onto the arms.

During the initial tests of these straps, an interesting discovery was made. The perceived depth of vibration was found to be a function of the tightness of the strap. Specifically, the sensation of vibration was most superficial with the strap adjusted just tightly enough to hold the transducer in place. As the strap was tightened, the vibrations moved deeper into the skin and eventually into the bones. This phenomenon has a simple mechanical explanation: when the straps are loose, vibrational energy is transferred only to the skin.

Tightening the straps couples the transducer with the underlying bone structure, causing vibrational energy to be imparted to both the skin and bones.

4.3 Hardware interface

A means of independently driving the transducers was required. The V1220 transducers perform a similar function to that of loudspeakers – they convert electrical signals into vibrations. Thus the same signals which are used to drive speakers could be used to drive the transducers. Accordingly, it was decided to take advantage of commercially available software and hardware tools for digital audio editing and production. The Digidesign Protools LE / Digi001 package was chosen because of its versatility, extensibility, and strong support base. The Digi001 multiple-output external audio interface is connected to the parallel port of a Macintosh G4 and performs 24-bit D/A conversion to produce the analog signals for the transducers. The actual synthesis of the signals happens in software running on the G4 and is explained below. The outputs of the Digi001 are fed into a 12-channel, adjustable gain amplifier unit designed by the author. This unit amplifies the low-voltage output from the Digi001 box, providing the 0-10 volt input signal required for the transducers. The gain of each channel can be adjusted independently to provide additional control over the relative intensities of the transducers. The transducers are connected to the amplifier outputs by twisted-pair cables, 6 ft. in length, made from 22-guage wire. Essentially, the setup uses the audio outputs of the Digi001 - which would normally be routed to an audio amplifier and used to drive a set of speakers - to drive the transducers of the vibrotactile stimulator.

4.4 Audio Source

During the design process, two sources were considered for the presentation of the audio component of a tactile composition: external speakers and headphones. An interesting issue arises when determining the optimal configuration of the audio source. When listening to stereophonic (two-channel) audio through external speakers, sounds are perceived to originate somewhere out in front of the listener. The angle at which the listener localizes a sound is dependent on the relative intensity of the sound in the left and right channels. A different scenario arises when using headphones, however. A stereo recording heard through headphones generally gives the impression that (1) the sound appears to come from inside the head, and (2) there is a definite sense of space, at least along the dimension stretching between the ears. Thus, a violin might appear to be at the left ear, while simultaneously a singer's voice might appear between the center of the head and the right ear. The within-the-head perception of such headphone-presented sound is referred to as *internalization* of the sound images; the differential placement of sound images along the imaginary line between the ears is referred to as *lateralization* of the images (Grantham, 1995).

This difference is made relevant in the present application by interactions between the auditory and haptic systems. A large variance may be observed between the perception of a tactile composition using external speakers versus headphones. Various cross-modal interactions between the senses of hearing and touch will influence the observer's sense of space. Specifically, the relationship between the location, in auditory and tactile space, of the respective stimuli will play an important role in the perception of a tactile composition. By manipulating the spatial location of the two components in different ways, the composer can create different illusions of motion and steer the observer toward certain kinds of perception. Subsequently, the kinds of perceptual effects he is able to create will depend on the method of audio presentation – with headphones, auditory space rests within the head of the observer while with loudspeakers, it rests outside of the observer's body. This topic is examined in further detail in Chapter 7. Further studies comparing the spatio-temporal effects of external speakers versus headphones on the perception of tactile compositions are warranted.

Another issue pertaining to the audio source relates to what might be called the "overall intimacy" of a tactile composition. In most cases tactile stimuli must be, if not in contact with, at least in close proximity to the body to evoke a response in the haptic system. For this reason, the sense of touch is often considered to be inherently more intimate than the other senses. On the other hand, auditory stimuli situated apart from the body can still be detected and processed by the auditory system. By using headphones to present audio stimuli though, the origin of the stimuli appears to lie within the head of the listener.

Thus we might expect the use of headphones to result in a more overall intimate experience of a tactile compositions; both the tactile and audio components appear to originate *on* or even *from within* the body.

One factor which warrants the use of headphones is transducer noise. Audio leakage from the transducers can distract the observer from the auditory component of a tactile composition and is thus clearly undesirable. The V1220s emit a buzzing noise when driven with inputs over 10 volts (resulting from the cantilever mechanism colliding with the plastic enclosure), but are relatively quiet when driven within the prescribed input range. The Interactor Cushion, however, tends to produce audible noise. During typical usage of the device with a musical source, as prescribed by its accompanying manual, there is a fair amount of audio leakage. This is to be expected since it is basically a speaker being driven in the audible frequency range. Granted, this leakage might be drowned out when using loudspeakers driven at high levels, this scenario is not always possible or desirable. Taking these factors into consideration, headphones were chosen as the audio source; they isolate the audio component from transducer noise and are generally more convenient. A pair of Audio-Technica ATH-M3X headphones with a closed-back design was used for this purpose.

4.5 Composition environment

The primary function of the composition environment is to provide an interface for composing in the tactile domain as well as a means of synchronizing the tactile and audio components of a composition. In this basic scenario, the composition process occurs in essentially one direction: from sound to touch. In other words, composition occurs only in the tactile domain, along with a fixed audio component which has been previously composed and recorded. Perhaps one day a parallel, multi-modal composition environment may be implemented in which one could explore the interplay between the composition processes in the respective modalities of audition and touch.

Once again drawing on a musical analogue, the initial conception of the composition environment drew upon the GUI paradigms on which many commercially available

multi-track $MIDI^{14}$ / digital audio sequencing and editing applications are based. The idea was to provide the composer with an intuitive visual representation of the multiple 'tracks' comprising a tactile composition; two tracks for the audio (left and right channels) component and one track for each transducer (or site of stimulation). Each track would display the appropriate waveform information with amplitude on the vertical axis and time on the horizontal. Clicking the mouse at a horizontal position on any track would advance all of the other track views to that same point in time. Different layouts of the tracks within the GUI were considered. One configuration involved the superposition of each track view over its respective site of stimulation on the body, with the audio component sitting at the bottom of the screen. This configuration is spatially intuitive, but less so temporally since the tracks are not vertically aligned. The GUI might allow the user to switch back and forth from this view to one where the tracks are simply stacked above one another with their time scales lined up. To enter information into each track, the user would specify a set of parameters including waveform and frequency and subsequently 'draw in' the desired waveform envelope into each track. Composing in this scenario might also involve entering a set of parameters into a *tactile pattern generator* which would automatically insert the appropriate wave data into the appropriate tracks. In any case, this general approach to tactile composition seemed far too tedious and not particularly intuitive.

The general paradigm for composing music using MIDI systems was given a closer look. In a typical MIDI composition scenario, a composer might enter a part into a sequencing program in real-time using a MIDI controller in the form of a piano keyboard. The set of parameters which is considered sufficient to play this sequence of notes back is stored in the computer on which the sequencing program is running. This information – as prescribed by the MIDI protocol – includes Note On / Note Off Event times, Note velocity, Note pitch, and a variety of note modulation events and is transmitted between devices by way of discrete packets. Once the sequence has been entered, the composer can subsequently make modifications to it. He might wish to correct a mistake made while entering the part. Alternatively, he might want to apply a modulation which he

¹⁴ Musical Instrument Digital Interface (MIDI)

could not perform simultaneously while entering the part (only two arms, ten fingers, and one cerebellum!). Most MIDI sequencing programs contain a host of features which allow the composer to alter a part after it has been entered. One can see the compositional power of such a combination of real-time and editing-based tools.

Tactile composition seems to fit very well within this paradigm. An analogy will now be drawn between the quintessential MIDI setup and the present system for tactile composition. This analogy is illustrated graphically in Figure 4.7. First, a device that facilitates the entering of parts in real-time is required. The Macintosh keyboard was chosen for this purpose. Most computer users are relatively comfortable with navigating a keyboard, making the learning curve rapid. As shown in Figure 4.6, the s,d,f,h,j,k, and spacebar keys corresponded, respectively, to the left hand, left elbow, left shoulder, right shoulder, right elbow, right hand, and back. We can also take advantage of the layout of the keyboard to give the composer a variety of real-time controls for entering a sequence. Three particular parameters which might be useful to control on the fly are frequency, waveform, and envelope. One drawback of using the keyboard is its limited ability to convey intensity information; in MIDI systems this is referred to as *Note Velocity* and encodes information on how hard a key is pressed. To overcome this limitation, a foot pedal which would allow the composer to modulate the amplitude of tactile stimuli in real-time was considered (to be used in conjunction with the Mac keyboard). Time constraints prohibited the implementation of this feature, however.



Figure 4.6. Command layout on the Macintosh keyboard. By placing the ring, middle, and index fingers of the left hand on the s,d,f keys, respectively, and the index, middle, and ring fingers of the right hand on the h,j,k keys, and the thumb on the *spacebar*, the composer has an intuitive spatial mapping from fingers to sites of stimulation on the body.

Next, our equivalent of a MIDI sequencer is a MAX/MSP program which can record and play back sequences entered via the keyboard. Optimally, this sequencer would be capable of storing a variety of parameters – such as envelope, duration, frequency, waveform, and intensity – which comprehensively describe each event. In addition, this sequencer would optimally provide a visual representation of these events and allow the composer to subsequently change the value of any parameter after a sequence has been entered. Due to limitations of the software tools used as well as time constraints, however, the sequencer actually implemented does not include a visual representation of recorded sequences and consequently has no means for altering parameter values after a sequence has been entered. The sequencer implemented is presently capable of recording only timing and duration information – i.e. note on and note off.

A somewhat ad-hoc process was devised to overcome these limitations. Let's assume that a composer has entered, in real-time, the basic skeleton of a composition into the sequencer. Using the GUI, he would then export the transducer tracks as individual $AIFF^{15}$ files. These files could then be imported into Protools LE – the software editing environment packaged with the Digi001 setup – as separate tracks at which point they can be altered using a variety of audio editing tools. Once the tracks have been imported in ProTools, the composer has both a visual representation of the composition as well as a

¹⁵ Macintosh format for a digital audio file.

means for editing all aspects of the composition including frequency, waveform, timing, spatial placement, and envelope. Although the use of the Protools/Digi001 setup is somewhat of an overkill with regard to the high quality of the audio outputs, the ProTools LE software environment facilitates the activity of multi-modal composition (discussed in Section 11.2) by providing a single environment in which musical and tactile composition can take place in parallel.

Finally, the equivalent of the MIDI synthesizer for this system is a software module (also implemented in MAX/MSP) which takes messages from the sequencer as its input and outputs the appropriate signals to the vibrotactile stimulator. Please note that a block diagram illustrating the various modules and interconnections of the composition environment is included in Appendix A. Taking the whole analogy just one step further, the amplifiers and speakers used to listen to sounds produced by a synthesizer are analogous to the amplifier and transducers comprising the vibrotactile stimulator in the tactile composition system.



Figure 4.7. Typical MIDI setup and tactile composition system shown in parallel.

The reader is reminded that the system described above represents one of the first steps towards the realization of a set of tools for tactile composition. It is relatively simple and somewhat limited in several respects. The author believes that a large part of its utility is as a model for approaching the design of tools for tactile composition. At the same time, the author asserts that the compositional power of this system is great and the possibilities for creation, endless. One of the primary goals of future design iterations of the system will be the design of intuitive, flexible interfaces for composing in the tactile modality.

5 A compositional language for the sense of touch

O'Modhrain (2000) explains that we lack the tools which will allow us to develop a language for the basic building blocks of our haptic world in the same way as we can talk about pitch, timbre, spectra, and envelopes of sounds. This largely stems from technological limitations; researchers are still having to build tactile and haptic displays designed to test specific sensory responses. Granted it is not yet possible to develop a comprehensive language describing the universe of haptic sensations, by limiting our scope to a specific tactile response – in the present case, the vibrotactile response – we can endeavor to identify the underpinnings of a compositional language. Furthermore, this endeavor is facilitated by the strong analogies that exist between sound and vibrotactile stimuli and, consequently, music and tactile composition.

A discussion on any language can take place at various levels of abstraction. Tactile composition is in its infancy and thus the present discussion will be concerned with the very lowest level of language; specifically those dimensions of tactile stimuli which can be manipulated to form the basic vocabulary elements of a compositional language. Geldard writes: When one is working so close to the foundations of an edifice, there is high probability that anything accomplished will turn out to be important for the superstructure ultimately to be erected (1960). Along these lines, it is hoped by the author that as technology advances and we have more versatile tactile stimulation devices at our disposal, the ideas and general approaches taken here will be extensible to the formation of a more comprehensive compositional language accounting for all of the tactile responses.

As elicited in the background chapter, the skin is capable of a range of spatial and temporal discriminations. The following discussion is aimed at answering two fundamental questions: *Which of these discriminations will form the building blocks of a compositional language for the sense of touch? And how will they do so?* To answer these questions, we will draw some analogies with – and discuss some important differences between – music, tactile speech communication, and tactile communication schemes in general.

The intrinsic similarity between tactile speech communication and tactile composition, namely a transformation from sound to touch, was pointed out in Chapter 2. We turn now to some important distinctions between the two fields, which will allow us to sift out those elements of the body of tactile speech communication research that are most applicable to tactile composition. The first distinction deals with the designation of speech as a medium for communication. The overall goal of tactile speech communication is to provide a channel other than sound for the transmission of information via speech which, as a language, is often viewed as encoding hard *information.* Music is often construed as a language of communication, but few people would consider music to constitute hard information. There is an extremely large amount of variability in the meaning of a piece of music across listeners – orders of magnitude more than for speech. Thus tactile composition does not strictly implicate the *encoding* of musical information. Rather, the relationship between the audio and tactile components of a tactile composition is more loosely defined and can extend far beyond the relatively narrow notion of an encoding or transformation. The tactile component may simply represent an interpretation of the music – in the case of parallel composition in the two modalities, the components might even be interpretations of each other. Alternatively, the tactile component might represent another "compositional strand" which has a more complex and interactive relationship with the music.

The second distinction deals with differences in the underlying audio signals to which the tactile components are coupled: speech versus music. Speech and music both comprise expansive sets of stimuli with much dynamic and temporal complexity. It is safe to say, though, that the frequency range found in music is significantly larger than that of human speech. Granted, the frequency response of the skin is the same regardless of the application, the domain of frequencies being mapped into the vibrotactile frequency range of the haptic system is significantly larger for music than it is for speech. Although tactile composition does not presume the notion of a mapping from music to touch, such mappings will undoubtedly be utilized in the compositional process.

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Efforts have been devoted to the formulation of various schemes for tactile communication, some of which were mentioned in section 3.3.2. There has been a considerable amount of interest in the design of tactile navigation systems. Potential users of such systems include persons who are blind, pilots, astronauts, scuba divers – all of whom need to maintain spatial awareness in their respective unusual environments (Cholewiak & Collins, 2000). Situations in which sound alone is not a sufficient medium of communication might also warrant the use of tactile communication systems. Geldard considers the skin's ability to receive a language in the narrow sense of a complex impersonal system of symbols like Morse, semaphore or even English (1966). He cites four discriminations in time and space on the skin, which may provide vocabulary elements in a scheme for the tactual encoding of hard information: duration, frequency, intensity, and spatial location. In the range from 0.10 to 2 seconds, the skin can distinguish approximately 25 discrete, just-noticeable differences (JNDs) in length, at least four or five of which can be judged with absolute correctness. With respect to intensity, around 15 JNDs can be detected between the threshold of detection and the discomfort level (Geldard, 1966a). As demonstrated by these enumerations, the approach taken by Geldard – namely the consideration of discrete JNDs – is indicative of the application, which requires uniquely identifiable stimuli.

While a virtually identical set of stimuli dimensions will form the basic vocabulary elements of a language for tactile composition, the inherent nature of their manipulation will differ in the case of tactile composition. There is no stringent requirement to work on an absolute recognition basis with respect to identifiable differences in frequency, duration, intensity, and space. The goal is not a consistent interpretation of an encoded message. Rather, we are concerned more with *aesthetic perception*, which Behrend explains is similar in kind to ordinary perception, but allows freer reign to imagination and emotion (1998). Accordingly the parameters values employed in tactile composition will exhibit more continuity over their respective ranges. In addition, parameter differences between stimuli can approach the haptic system's discriminatory limits.

This point raises some interesting issues. For one thing, complex spatio-temporal patterns which push the limits of the haptic system's ability to detect, identify, and discriminate, may form *tactile landscapes*. In other words, higher level patterns and sensations can emerge from complex combinations of stimuli which, on an individual basis, may not be easily resolvable or resolvable at all. Truax explains that in musical perception it is often the way in which various parameters combine to form a whole that is more important than the pattern of organization of any one parameter (1986). Perhaps the notion of tactile landscapes would best be illustrated by considering the holistic nature of music. At some point, most music listeners have "dissected" a song into its individual parts while listening to it, focusing their attention on one part at a time. Music is usually perceived very differently when listening in this manner, compared to the way it sounds when listening to it holistically. Sometimes these gestalt-like shifts are not easy - or possible at all - due to the high level of intricacy or complexity of a particular piece of music. This does not preclude, however, the holistic perception of the piece; the complex, indiscriminable parts can still combine to form a synergistic sum that is plainly recognizable as a piece of music. Furthermore, these so called tactile landscapes will be perceived differently from observer to observer. This is presumably a desirable situation - similar to a good piece of music, a tactile composition may feel differently each time it is experienced. The amount of variation in the perception of these patterns will depend on the complexity of the patterns as well as selective attention mechanisms operating in the mind of the observer.

The more fundamental building blocks there are – synonymously, the more useful stimuli dimensions there are to manipulate – the more power and versatility there is afforded to a language. In the case of tactile communication schemes, this translates to the ability to encode a larger body of information. For tactile composition, this means a richer, more versatile set of tactile sensations with which to work. Pellegrino feels that the electronic arts of sound and light are so attractive because they present a virtually infinite field of forms and structures to be explored. Every combination of frequency, amplitude, waveshape, and their individual and combined envelopes results in a different form (1983). The salient dimensions of tactile stimuli, outlined below, combined with those

elements of sound and music form a versatile set of basic vocabulary elements that may be combined to yield an infinite amount of forms and higher-level compositional structures. We will now proceed to think about how to form the basic vocabulary elements of a compositional language for the sense of touch. The spatio-temporal discrimination abilities of the skin are divided into five categories: duration, frequency, spectral content, intensity, and space. Table 5.1 is provided as a reference for the following discussion.

Psychophysical Dimension	Range		JND	JND on absolute identification basis**	General comments on compositional relevance	
	Auditory System	Haptic System	Haptic System	Haptic System	Music	Tactile Composition
Duration	> 0 s.	> 0 s.	25 ^a (from 0.1 to 2 s.)	$4-5^{a}$ (from 0.1 to 2 s.)	Rhythmic phrasing; Staccato/ legato articulations	< 0.1 s perceived as tap rather than vibration
Frequency	20- 20,000 Hz	20- 1000 Hz	Frequency dependent smaller at lower frequencies	~ 8 - 10 ^b	First order dimension; psychological correlate is pitch	Second order dimension of qualitative value: low-freq => buzzing, hi-freq=> smooth, diffuse sensation
Spectral content	-	-	-	-	Psych correlate is timbre; aids in separation of voices; allows for variations in sonic texture	Qualitative use: Spectrum from sine to square to noise perceived as smooth to rough ^b
Intensity	0–120 dB SL	0-55 dB SL	15 ^a (from detection threshold to just under discomfort)	3ª	Dynamic articulations; attack / decay of sounds; overall level i.e. pianissimo to forte	Dynamic articulations: crescendo/decrescendo; overall dynamic level; envelope is salient perceptual dimension
Space	180 deg. azimuth *	Entire surface of body		Frequency & location dependent (density and type of receptor stimulated)	Second order dimension; placement of sounds in stereo space	First order dimension, apparent motion on skin, spatial phrasing

(a) (Geldard, 1966a); (b) (Rovan and Hayward, 2000)

Table 5.1. Psychophysical dimensions of sonic and tactile stimuli and their applicability to music and tactile composition, respectively. Note that all values describing the haptic system specifically for vibrotactile stimulation. *The parameter values for space are given with respect to the azimuthal localization, which best captures the listening scenario of the stereophonic loudspeaker setup typically used for music. **These values divide the entire range of the system for any given dimension shown.

5.1 Duration

Although not necessarily the case, the timing and duration of the tactile events in a tactile composition will likely coincide with those values of corresponding musical events. Hence virtually no limits are imposed on the range of stimuli durations used in tactile composition. Durations below 0.10 s. are perceived as taps or jabs against the skin,

providing the tactile equivalent of musical staccato. Longer duration stimuli with different amplitude envelopes, on the other hand, may be used to construct more smoothly flowing tactile phrases. From the author's experience, differences in duration partly provide the variation needed to layer perceptually differentiable voices simultaneously on the same area of skin. For instance, most subjects are able to selectively attend to two lines that are simultaneously presented to say, the left arm, if one line consists of longer duration stimuli with slowly varying envelopes and the other consists of shorter duration stimuli with rapid onsets.

5.2 Frequency

The vibrotactile frequency range of the skin spans a range from about 20 to 1000 Hz with maximally sensitivity around 250 Hz (frequencies below 20 Hz can be perceived by the haptic system, but they are perceived as motion rather than vibration). Several studies have indicated that the skin is rather poor at discriminating frequency differences and that its limited ability to do so decreases as frequency increases (Verrillo and Gescheider, 1992). There is one additional difficulty where vibratory frequency is concerned. Geldard points out that the correspondence between vibratory frequency and perceived "pitch" is a tenuous and uncertain one. Vibratory pitch proves to be a joint function of both frequency and amplitude (1960). As a result, frequency will not be the most salient dimension of manipulation for tactile composition. This scenario is different from that found in music where pitch – the perceptual correlate of frequency – is a first order dimension. Unlike tactile composition, music can capitalize on the exquisite frequency analysis abilities of the auditory system.

In the least, frequency will represent a dimension of qualitative manipulation for tactile composition. Subjects in psychophysical experiments have reported a sensation of periodicity or buzzing at low frequencies (below 100 Hz) while at higher frequencies, a more diffuse, smooth sensation is perceived (Verrillo & Gescheider, 1992). This type of difference in sensory quality can be exploited as a basic element in a compositional language.

5.3 Spectral content

Related to the idea of sensory quality is the spectral content or waveform of tactile stimuli. Due to the skin's poor frequency analysis abilities, subtle variations in spectral content cannot be perceived in the way timbre is by the auditory system. Subjects are able, however, to observe the qualitative differences between say, a sine wave and a square wave presented to the skin, perceiving them respectively as smooth and rough. Given the data for frequency discrimination on the skin, it is clear that wave-form variations in general should be discriminable if the fundamental frequency is low enough (Geldard, 1960). According to Rovan and Hayward, the vibrotactile gamut from pure sine tone to frequency-rich spectrum to noise is characterized as a continuous transition from smoothness to roughness (19??).

5.4 Intensity and envelope

Between the limits of absolute detection and discomfort, the average observer, under laboratory conditions and with the use of a careful psychophysical procedure, can detect about 15 steps of intensity. On an absolute identification basis, the number of steps is more like three (Geldard,1960). Tactile composition calls for a continuum of intensities ranging from threshold of detection up to, but not including, the limits of discomfort. (Of course, this is a subjective range in that the limits of threshold and discomfort will vary from person to person). In this way, the tactile composer can construct higher-level dynamic articulations such as *crescendo*, the gradual increase in the intensity of a passage. By drawing from the entire continuum of intensities, we also allow for subtle dynamic variations in a tactile composition. These variations may be readily perceived, they may be appreciated only after extensive training, or they may only be received and processed subconsciously. In any case, they will contribute in some way to the aesthetic power of a compositional language.

Of particular utility is the envelope - variation of the intensity of a signal over time - of tactile stimuli. When talking about the envelope of sounds, the change in intensity at the onset and offset of a stimuli are often considered, referred to respectively as *attack* and *decay*. The attack and decay of tactile stimuli can be varied to create a variety of

perceptual effects. For instance, an abrupt attack will be perceived as a sudden tap against the skin whereas a more gradual attack, as described by one subject, seems to "rise up out of the skin." By applying subtle variations to the attack of a stimulus, it is possible to generate a continuum of sensations between these two extremes. The amplitude of a signal might even be modulated to create more complex envelope-related effects such as vibrato. In general, when performing more direct mappings from the music to the tactile domain, a composer might apply envelopes to tactile stimuli which mimic the envelopes of their sonic counterparts.

5.5 Space

Finally, we come to the realm of perception in which the skin shines brightly - space. As far as our spatial senses go, touch comes in second after vision. The spatial acuity of the skin is quite impressive. Many vibrotactile stimulators are designed with this acuity in mind, operating on relatively small areas of the skin (Optacon; Bliss *et al.*, 1970). As explained in Chapter Four, the use of the entire surface of the body seems more justified in the case of tactile composition. Correspondingly, we will expand our discourse on space to a larger domain: the universe of the skin in its entirety.

Of particular compositional value is the class of phenomena known as apparent motion on the skin. When applied over relatively large areas on the surface of the body, apparent motion phenomena can result in some extremely vivid sensations ranging from a miniature rabbit (of the cutaneous species) darting up the arm to little vibrating bugs crawling across the skin. Different patterns and types of apparent motion may be sequenced and layered to create a complex "vibrotactile dance" on the skin. Since there is no requirement for absolute identification of such patterns of motion – as there would be in a tactile navigation system – these patterns can potentially be imbued with high amounts of complexity, resulting in different perceptual outcomes between sittings and across observers. In addition, the *spatial envelope* of a pattern can be manipulated to yield even more variation. Spatial envelope describes the relative intensities at different points in space with respect to time. Another way to look at apparent motion is that traveling waves are being created on the surface of skin; the classic wave equation

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describes the pressure and velocity of a traveling wave in both time and space. In the case of tactile composition, spatial envelope broadly refers to the relative intensities of the set of transducers activated in a particular pattern with respect to time. The idea of spatial envelope introduces the notion of higher-level articulations which involve the use of space on the skin.

The discussion is now raised to a higher level of abstraction - the musical construct of rhythm. Rhythm is the concept that includes time relationships in music, in particular, the starting points and durations of individual sounds, and higher-order similarities arising out of patterns among these properties of sounds in musical contexts (Howe, 1975). Because frequency will not constitute a first order dimension, the musical construct of melody does not have a tactile counterpart. It is thus hypothesized that rhythm will assume a high level of importance for tactile composition. As is the case of music, tactile rhythms are of a temporal nature. Tactile rhythms will also have an additional facet not typically encountered in music¹⁶: a spatial component. In addition to the situation in time of tactile events, location in space will prove to be a powerful dimension for tactile composition.

More generally, the dimension of tactile space might be construed as a parallel to the concepts of structure and form in musical composition. A musical phrase is grouped – stylistically by the composer or cognitively by the listener – according to melody, temporal structure, and dynamics. Although probably not by melody, tactile phrases will likewise be grouped by temporal structure and dynamics. Furthermore, the spatial element leads to the idea of a *spatial phrase*; the grouping of tactile events according to their location on the body. The spatial phrase should prove to be a source of variation in the perception of tactile compositions.

¹⁶"typically" is used here because one might consider the stereophonic placement of sounds in azimuthal space as a spatial component of musical rhythms. In addition, effects such as reverb are often used to give the listener a sense of space. These are not, however, thought to be first order characteristics with respect to musical rhythm.

6 Composition-related issues

So far we have looked at the physical dimensions of vibrotactile stimuli and subsequently thought about how some of these can form the building blocks of a compositional language. In subsequent sections of this paper, some of the ways in which these and other variables influenced the design of a system for tactile composition will also be discussed. Let us now turn our attention to some of the issues that arise – from psychophysical and other factors – in the actual process of composing in the tactile modality. Each issue is identified, followed by a discussion of its pertinence to tactile composition and some possible strategies for dealing with it.

6.1 Psychophysical factors

In addition to the aforementioned importance of considering the psychophysics of touch for the design of a tactile stimulator, many of the psychophysical phenomena addressed in Chapter 1 have implications for the tactile compositional process. Because the language of tactile composition is effectively infinite in size and is not constrained by any rules, the tactile composer must be cognizant of the perceptual phenomena associated with tactile stimulation of the skin when making compositional decisions. Especially at this early stage in the development of tactile composition, where the composer is working with the most basic vocabulary elements of tactile stimuli, compositional decisions and the compositional problem-solving process must be informed by the psychophysics of the skin. The author foresees that the tactile feedback received during composition will serve to quickly orient the composer to these factors, providing a working knowledge of psychophysical effects such as adaptation and masking. One can read dozens of quantitative psychophysical studies on these phenomenon, but a practical understanding of them can only be gained through experience.

As discussed in Chapter 5, there is no need in tactile composition to strictly adhere to stimuli and patterns that lie within the discriminatory limits of the haptic system. The compositional spectrum from very dramatic to very subtle percepts will traverse the ranges and acuities of the skin's temporal, intensive, and spatial responses. In other words, as the limits of discrimination are approached, there is a higher likelihood that

patterns will be perceived differently by different people. The end percept of tactile patterns falling within what is generally considered to be a discriminable range will be more consistent across listeners.

Of particular relevance to tactile composition are the psychophysical phenomena of masking, suppression, summation, and enhancement. There are a few things to note about these phenomena. For one thing, studies on these phenomena tend to be concerned with the *detection* of stimuli in the presence of other stimuli, i.e. their effects on absolute threshold. Thus the results in the literature reflect a very limited set of circumstances which are unlikely to arise in the course of a tactile composition. For example, if a composer wishes to definitively draw the feeler's attention to a specific pattern or part of the body, which in a suppression framework would be called the target area, he might choose to lower the intensity of some pattern occurring simultaneously at a different body site. Along similar lines, these phenomenon and the underlying mechanisms of selective attention will undoubtedly come into play when layering different parts within a tactile composition. For instance, a composer might superimpose, on the same arm, a punctuated staccato-like phrase over a more diffuse slow-moving pattern. From the author's initial experiments with layering, it quickly became apparent that the brain can shift its attention from one tactile phrase to another just as in music it can scan and separate the parts of a piece with multiple voices.

In one study (Geldard and Sherrick, 1965), 10 vibrators were situated at different loci over the surface of the body. One vibrator was set at 15 dB SL and the other nine were matched in subjective loudness by the subject. The loudness produced by one vibrator was not great, but when all then vibrators were energized simultaneously, the overall feel of the resulting pattern was very much more noticeable than was that of any one vibrator. As the 10 vibrators were turned on, the subjects reported a 'squeezing' sensation of great magnitude (Geldard, 1966). This notion of vibrotactile loudness addition was explored further by Craig (1966) and is particularly relevant to the device presented in this paper, which presents vibrotactile stimuli to distributed points across the surface of the skin. Adaptation must be seriously considered in the context of tactile composition. The composer must be wary of its perceptual effects when making certain compositional decisions. This might entail, for instance, avoiding stimuli of long duration in one region and instead using pulses of shorter duration temporally spaced over several body sites. Or perhaps the effects of adaptation might be harnessed stylistically. The composer might want a stimulus to persist, but fall into the background of the composition. In this particular scenario, knowledge of the skin's anatomy – in particular, the frequency selectivity of mechanoreceptors in the skin – is also of much practical use to the composer. If a pattern using 150 Hz stimuli is intended to fall into the background while a different pattern suddenly appears in the foreground, the composer might use a higher frequency for the new pattern, say 400 Hz, stimulating the Pacinian corpuscles that were not significantly adapted by the 150 Hz stimuli.

As explained in the background chapter, the mechanoreceptors in the skin are tuned to different frequency ranges. As illustrated in Table 2.1, the two most important receptors for vibration are the Pacinian and Meissner's corpuscles, with frequency ranges, respectively, of 400-800 Hz and 10-200 Hz (The reader should note that the ranges to which these receptors are most sensitive are, respectively, 200-300 and 20-40 Hz). When using stimuli of varying frequencies in a composition, the composer must be aware not only of the resulting sensory quality of different frequency ranges and the frequency response curves, but also of the receptive fields of the receptors. The receptive field for the Meissner's corpuscles is an order of magnitude smaller than that of the Pacinian; the median receptive field for the Meissners has been found to be around 12.6 mm² while that of the Pacinian is 101 mm². Thus a stimulus complex presented to any given body site will feel more or less diffuse depending on the frequency of the stimulus. If the composer wishes to create a sensation of flutter which is perceived to be isolated to the site of stimulation, a frequency in the range of 20-40 Hz would be appropriate.

6.2 The spatial effects of posture

The tactile composition system presented herein works primarily through the vibrotactile channel. The two broad channels of haptic perception are not wholly independent,

however. Although it is not directly stimulated, proprioceptive perception is undoubtedly involved when wearing a tactile display that stimulates multiple body sites. The feeler's body position and movements during stimulation will determine the types of sensations he experiences. For example, a saltatory (sensory saltation discussed below) vector traveling from the hand to the shoulder will be perceived to move downward with respect to gravity when the arm is raised and upward when it is hanging at the feeler's side. Another way to frame this discussion is in terms of exteroceptive versus interoceptive and proprioceptive sensations. The exteroceptive sensations are initiated by the tactile stimulation device while the interoceptive and proprioceptive sensations originate from within the body, the proprioceptive sensations in particular based on the position of the body. According to Galeyev (1993), intereroceptive sensations act on the unconscious, and they are tied to our most basic emotions. These sensations, he claims, are ancient and are part of the psychologies of all people. He stresses the importance of such sensations as components of synesthetic interrelationships i.e. interactions between the five senses.

When composing a piece of music, it is not crucial to take into account the position or movements of the listener. The auditory percept of a piece of music might be altered when the listener turns his head or moves his body, but most of the time the change will be negligible. In the haptic modality however, the feeler's body position will have a nonnegligible effect on the perception of a composition. Compositional choices will be affected by assumptions made concerning the body position of the feeler. Should the composer assume that the feeler will remain relatively still in a comfortable upright seated position? Or should he compose with the possibility of different postures or even movement in mind? Perhaps tactile compositions will be accompanied by instructions suggesting which posture to take and when. The effects of body posture might even be utilized stylistically in a performance, for example, by asking the audience to assume different postures at various points in the piece.

The posture issue highlights the importance of frame of reference for tactile composition. Tactile stimuli tend to be referenced by the observer to his own anatomical features. For

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instance, the most salient frame of reference for apparent motion on the skin is the body itself; the cutaneous rabbit hops from my right hand to my right shoulder and back down the other arm. But what about considering this motion in the gravitational frame of reference of that of the observer's surrounding environment?

It turns out that for certain patterns, especially those which traverse the center of the body, this external frame of reference plays a role in perception. For instance, consider the alternated presentation of a short vibrotactile burst between the left and right hands. From experience, the author has found the resulting percept to be a 'bouncing' of the stimulus between the hands. If the hands are held together, this stimulus bounces a relatively short distance, following a straight trajectory between the hands. Alternatively, if the arms are held out to the sides, perpendicular to the body, the stimulus has a much longer distance to bounce; at times, it almost feels as if it is bouncing *through* the body along the length of the arms. As mentioned above, body position also has a salient influence on the perception of saltatory signals. The path of these signals with respect to the anatomical features of the body (joints in particular) is constant regardless of position, but their path through the three dimensional space around the observer is a highly dependent on body position and correspondingly, proprioception.

In music, there is the widely recognized conception of tension and resolution with respect to the harmonic and melodic motion of a composition. It turns out that similar ideas apply to apparent motion on the skin (examined further in Chapter 7). Body position plays heavily into this psychological phenomenon of anticipation. For example, imagine that while experiencing a composition using the Skinscape system, you are holding your arms out in front with the fingers of the left and right hands just touching. Now picture a saltatory signal that traces the loop formed by your arms, i.e. down the left arm, across the hands, up the right arm, down the left arm, and so on. Suddenly this cyclic pattern of hapto-kinetic motion is broken and the signal suddenly gets 'caught' in your hands, bouncing back and forth between them. This simple compositional sequence begins to illustrate the effects of position on the observer's anticipation of motion.

6.3 Relative 'volume' of components

Psychophysical research has historically been concerned with determining relationships between subjective magnitude judgments across sensory modalities. For example, how do we relate the *brightness* of a light to the *loudness* of a sound? With regard to the relative overall subjective magnitude of the audio and tactile components of a tactile composition, the question arises: Is there an intensity level – relative to the overall intensity level of the tactile stimuli – at which the audio component can be played so that it essentially "drowns out" the tactile component of a tactile composition? Further experimentation is needed to answer this question, but intuitively it seems that the sheer physical proximity of tactile stimuli might be enough to hold the observer's attention, regardless of how loud we pump the music. The approach taken toward this issue might be left wholly to the discretion of the composer. A composer might superimpose high-intensity, rapidly moving tactile patterns on top of a gentle, harmonious musical passage to create an interesting (depending of course on the skin of the beholder) effect.

6.4 Complexity

Another important issue to consider is complexity, in particular the relative complexity of the musical and tactile components of a composition. In the frequency dimension, the tactile component cannot come close to matching the harmonic complexity of music. This follows from the poor frequency analysis abilities of the skin. On the other hand, the tactile component can far exceed music in spatial complexity. As hinted at in previous chapters, as the complexity of the tactile component is raised to a level at which patterns are no longer individually discernable, "tactile landscapes" may emerge in which the complex sum of many simple patterns is synergistic.

It would be narrow minded to say that the complexity levels of the two components must always be compatible. As with many of the factors addressed above, the dimension of complexity might be approached stylistically. For example, the tactile component might serve to emphasize a single voice in a complex musical composition containing many layered voices and, therefore, can be relatively simple. At certain points in a

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composition, a composer might 'starve' the listener's sense of touch by dropping out the tactile component altogether. The composer, however, must be perpetually cognizant of the relative levels of complexity of the musical and tactile components.

7 Cross-modal interactions

Despite the view commonly held by human beings, the five senses do not operate independently. Current knowledge of the physiology of the brain shows that the superior colliculus is one of the sites in the central nervous system in which a convergence of visual, auditory, and somatosensory inputs occurs. Consequently, there are a number of interesting phenomena resulting from the stimulation of multiple senses. The combination of auditory and tactile stimulation present in tactile composition, as conceived in this paper, paves the way for a host of interesting and compositionally valuable perceptual phenomena involving sensory interactions. This chapter presents a brief background on cross-modal sensory interactions, provides several examples, and begins to hint at how such interactions between hearing and touch may be harnessed for compositional purposes.

7.1 Overview of sensory-interactions

Begault writes that our collective knowledge of psychoacoustics far exceeds our knowledge of the multi-modal interaction between sight, audition, and tactile sensations (1999). It turns out that perceptual phenomena demonstrate that interactions among different sensory modalities must exist in order to use them together effectively (Stein and Meredith, 1993). Although there is a substantial amount of evidence about the location in the brain where inputs from different modalities converge, there is no significant body of literature describing the specific neural mechanisms of observed intersensory phenomena (Stein and Meredith, 1993). It should be noted that the study of multimodal interaction, primarily between audition and vision, has received increased attention with the development of virtual reality systems, home theater, gaming and teleconferencing (Begault, 1999). There has also been a renewed interest in the intersensory phenomena known as synesthesia. Several general classes of multimodal perceptual phenomena have been discovered and studied.

In psychology, the term 'ventriloquism effect' refers to the phenomenon of intersensory bias, where, for example, vision can influence judgments about proprioception and audition, proprioception can bias auditory judgments, and so on (Stein and Meredith, 1993). The magnitude of intersensory bias and the dominant modality depend on how compelling or real each individual cue is (Welch and Warren 1986). The cues can be weighted very differently when combined with one another, and it is their final integrated product that determines the perception of, and the reaction to, an event. Interactions between senses can also be of a cooperative nature, affecting, for example, a person's reaction time to a stimulus complex. The functional synergy among sensory systems carrying concordant information is evident as an increase in overall reaction speed, as well as in the physiological processes that signal the presence of the stimulus complex (Stein and Meredith, 1993).

7.2 Interactions between audition and touch

A thorough investigation into the intersensory phenomena involved with audition and touch is beyond the scope of this paper – this is left to the psychophysicists, physiologists, and psychologists. At the same time, a working knowledge of these interactions will likely be built from experience with tactile composition. There is a universe of perceptual effects – some quite dramatic and others very subtle – to be explored with regard to multimodal interactions in tactile composition. Here, a rough sketch is given of some potential scenarios in which intersensory interactions between hearing and touch may be applied in a composition context.

One perceptual dimension that has great potential for exploration with regard to intersensory phenomena is that of space. Both audition and taction are - to different degrees - spatial senses. There is much that can be done between these senses to transform the observer's sense of space on and around the body. For example, as touched upon in a previous chapter of this paper, depending on the source of the audio – loudspeakers or headphones – different manipulations of auditory space can be accomplished. Anecdotal evidence obtained by the author shows that when using headphones, the simultaneous presentation of temporally synchronized tactile and audio stimuli can create the astounding illusion that the sounds are originating from various points within the body! Alternatively, when the method of audio presentation is loudspeakers, an observer might construe the combined sensation of audio and tactile
stimulation as sound waves being shot down the barrel of a gun, landing at various points on the body; in a sense little sonic bullets.

A more straightforward, yet powerful application of intersensory phenomena involving space is the mutual reinforcing effect that the manipulation of tactile or auditory stimuli complexes can have on each other. For example the placement of a sound between the left and right ears might be reinforced by the mapping of stereo space onto the length of the arms. Furthermore, the manipulation of space in the tactile modality can expand the sense of space possible in the auditory modality alone. For instance, simulating changes in the apparent elevation of recorded sounds using only two-channels of audio is not easy. To this end, we might imbue sounds with altitude – and an enhanced sense of three-dimensional space in general – by adding a tactile component that maps the sounds onto the length of the arm or even better, the height of the body from head to toe. Another interesting compositional technique would be to map different instruments in an orchestra to different locations on the body, a "part-to-place" mapping, creating the illusion of an invisible orchestra distributed across the surface area of the skin; the tympani against the back, the bassist on the left shoulder, the cellos on the elbows, the violins on the wrists, etc. Oppositely, a composer might wish to essentially confuse the observer, presenting conflicting auditory and tactile cues. Such compositional techniques might be referred to as "cross-modal counterpoint".

Putting aside the idea of external tactile stimulation for a moment, music, on its own, has the ability to create - albeit subtle - variations in the physiological state of the skin. Perhaps the most powerful example is the "chills". At one time or another, every music listener has experienced the sensation of chills shooting through the body in response to a particularly emotionally stimulating piece of music. These chills are oft accompanied by goose bumps, the elevation of the hair follicles above the rest of the skin, which are caused by nerve discharges from the sympathetic nervous system. Another less obvious and not so perceptible change in the skin associated with music listening is conductivity. Researchers (Picard, 2000) have observed that the conductivity of the skin tends to be higher while subjects are listening to more energizing music and lower during relatively calming music. While these phenomenon do not directly or dramatically influence the perception of vibrotactile stimuli, they are worth mentioning as cross-modal phenomena. Galeyev (1993) emphasizes that not only may exteroceptive (externally stimulated) sensations act as components of synesthetic interrelationships, but interoceptive (internally generated) sensations may also contribute.

7.3 Music and the body

We often talk about music as being "visceral." We discussed above the direct physiological changes music is capable of inducing in the listener. The term visceral might also imply the reflex of say, cringing in response to an unexpected loud noise, or the rumbling sensation produced by high-intensity, low-frequency sounds in the gut. In addition to these somewhat obvious relationships with the body, music is considered visceral because it actually makes the muscles move – or at least makes us think about moving our muscles. According to Jourdain (1997), when a good ear follows good music, somehow even the deepest and most abstract relations seem to find expression in the body. We know that tonal-rhythmic patterns are very closely associated with the voluntary musculature, and very importantly influence its action. (Mursell, 1937). Jourdain points out, though, that the aud itory cortex is densely connected to other parts of the temporal lobes and with the frontal lobes, but not with the motor cortex that moves our muscles or the somatosensory cortex that monitors sensations in skin and tendon and muscle.

Jourdain purports that if music does not channel directly to our muscles, then we must consciously put it there. It seems that we use our musculatures to represent music, modeling the most important features of musical patterns by means of physical movements large and small. At one extreme, we bounce up and down to a pulsing beat. At the other, we are immobile yet are racked by anticipation of movement, experiencing impetus toward motions that we do not actually initiate (Jourdain, 1997).

Jourdain consents that this view is speculative, since there is no science of muscular representation, but suggests two logical reasons for such a representation. First,

representation provides a sort of notation system in which we momentarily inscribe features of music as it passes by, and thereby more easily remember those features over many seconds; for example encoding musical trajectories as muscular tensions and holding them until they are resolved. Second, muscular representation serves to amplify our experience of music. Musical patterns that produce emotion and pleasure are replicated in a second, particularly extensive neural system - the motor system - and so emotion and pleasure arise in this second medium as well as in the direct experience of sound. In a sense, we use our bodies as resonators for auditory experience.

One way to look at the function of explicit tactile stimulation in conjunction with music listening is the amplification of the visceral component of music. There is music which tends toward the more intellectual end of the spectrum - music which takes the mind of the listener for a ride more so than it does the body. This is compared to say, modern electronic dance music or hip-hop, which derive much of their musico-emotional power from more visceral characteristics. Thus by coupling the music with explicit, composed tactile stimulation, the bodily elements of so-called intellectual music can be elicited and intensified, resulting in an altogether more synesthetic musical experience.

So, at some level, we are already accustomed to the idea of an intricate corporeal element of music - this sense of musical motion unfolding on the skin and within the muscles. Jourdain believes that kinesthetic anticipations reside so deep in our existence that we hardly notice them, talking about the "invisible dance" that one can introspectively observe while listening to music. The intricate and aesthetically designed tactile component of a tactile composition essentially materializes this dance on the skin, making it not so invisible!

7.4 Tactile attributes of sound

There is a pre-existing link in our minds between musical sounds and tactile sensations. Mursell (1937) remarks that tone is found to possess very definite and consistent tactile values. We speak of a tone as hard or soft, rough or smooth. Low tones give the impression of a dull puff-puff; high tones are sharp, or keep, or cutting. The loosely defined characteristic of sounds relating to their texture, timbre, is also naturally expressed in tactile terms. Mursell proposes that the remarkable unanimity with which certain of these characteristics are attributed to certain sounds strongly suggests a connection more than associative and external between tone and tactile values (discussed further in section 7.4). Below is an excerpt from Simon Reynolds' *Generation Ecstacy* describing a particular synthesized sound used widely in modern electronic dance music:

Why is it so pervasive, compelling, undeniable? Because the "mentasm" sound captures that edge-of-darkness point at which Ecstasy's bliss becomes shadowed by foreboding, its warm glow turns into a cold rush. Abusers of stimulants like amphetamine and cocaine often suffer from 'crank bugs', the delusion that insects are crawling under the skin; the swarming rush of the mentasm sound feels like the bugs breaking through your skin and gathering in a gigantic buzzing locust cloud (Reynolds, 1998).

While this passage might or might not conjure up a pleasurable image in the reader's mind, it does - in a metaphorical and extremely vivid way - convey the salient tactile quality of one particular musical sound. Furthermore, it captures the highly visceral nature of electronic dance music and hints at the idea of audio-tactile synesthesia.

7.5 Tactile composition and synesthesia

We now consider tactile composition in the framework of *synesthesia*. According to Galeyev (1999), even encyclopedias and thesises lack uniformity in establishing a definition and limits of the term syne sthesia. The root of the word seems to lie in its definition as a medical condition in which one type of sensory stimulation evokes the sensation of another, as when the hearing of a sound produces the visualization of a color. Over recent centuries, it has gained a number of metaphorical and artistic connotations. The existence of synasthetes has been recognized as far back as the nineteenth century. The example of *sonogenic synesthesia*, in which music provokes intense visual experiences or cutaneous parasthesias¹⁷, has been known for well over 100 years (Critchley, 1977; Henson, 1977). Galeyev (1993) believes that the necessity to study synesthesia, its regularities and functions in art, is particularly important when considering a new artificial media, as in the case of 'visual music' in which both sound

¹⁷ A skin sensation, such as burning, prickling, itching, or tingling, with no apparent physical cause.

and image are synthesized. It seems that the development of tactile composition can be significantly enriched and informed by the current body of knowledge on synesthesia.

Cytowic (1995) explains that by the mid-nineteenth century, synesthesia had intrigued an art movement that sought sensory fusion. The union of the senses appeared more and more frequently in the writings of musicians and visual artists. Multimodal conerts of music and light became popular. Cytowic (1995) defines synaesthesia as the involuntary physical experience of a cross-modal association. That is, the stimulation of one sensory modality reliably causes a perception in one or more different senses. He sharply distinguishes its phenomenology from "metaphor, literary tropes, sound symbolism, and deliberate artistic contrivances that sometimes employ the term 'synesthesia' to describe their multisensory joinings" (Campen, 1997).

In all of the literature and web pages devoted to synesthesia, there is little to no discussion of the coupling of music with explicitly composed tactile stimulation, the focus being on the artistic coupling of music and light. By Cytowic's standards, tactile composition would constitute "sensory fusion"; in other words a deliberate artistic contrivance. While our primary concern here is not nomenclature – i.e. genuine synesthesia versus sensory fusion – a tentative argument is herein made which discusses the unique aspects of tactile composition that make it a particularly strong and in a sense, pure synesthetic medium. In the case of both visual music and tactile composition, cross-modal associations are contrived; they have been composed by the hand of a human or a machine. In both cases, the perceived multi-modal sensations are exclusively exteroceptive (generated externally with relation to the body). There is a subtle distinction to be made between the two, however. With visual music, the visual stimuli being coupled with the music are physically removed from the body, usually projected or displayed on a screen. In addition, they are experienced collectively by the audience; essentially the same photons are being received at everyone's eyes.

The egocentric nature of our sense of touch paints a different picture for tactile composition. The tactile stimuli of a tactile composition originate on the skin of the

observer. Granted, they are generated externally, they are in direct physical contact with the skin. Furthermore, the egocentric nature of our sense of touch precludes the 'collective' reception of a tactile composition. In other words, even though everyone in the audience is feeling the same stimuli, they are receiving these stimuli through their own 'private' display device and in their own personal space. To put it differently, if the observer temporarily forgets that there are electro-mechanical transducers resting against his skin, and experiences the illusion that these vibrations originate from within his own body, he is able to experience sensations which come very close to those experienced by a true synesthete; essentially a music-induced paresthesia.

We have all probably experienced a mild form of synesthesia while listening to music. Just as a piece of writing can conjure vivid images in the mind of the reader, a musical composition can incite the formation of images in the mind of the listener (The reader might notice that this pseudo-synesthesia is actually just the recall of visual memories being provoked by the music; nonetheless, the phenomenon is of a synesthetic nature and is relevant to the perception of a tactile composition). Now add a tactile component to the music. Keeping in mind that tactile stimulation alone can provoke the imagination, imagine the synergistic sum of sound and touch. A metaphorical way of looking at it is that the observer's brain is confused by this unnatural coupling of sound and touch and automatically concocts a 'story' to resolve it. By utilizing strong auditory and tactile cues, as well as imaginative and clever combinations of the two, the composer can drive the imagination of his audience into spectacular flights of visual imagery.

A simple example came when, while playing with spatial envelopes of saltatory signals, the author noticed a peculiar sensation. A saltatory signal was generated which varied in intensity as it progressed up the right arm, across the shoulders, and down the left. The tactile pattern was accompanied by a continuous sinusoidal sound with matching intensity envelope. As the train of taps decreased in intensity, the rabbit seemed to burrow down into the arm and then resurface as the taps gained in intensity. This might be explained by some cognitive mapping of the visual representation of the sound's intensity envelope onto a two-dimensional cross-section of the arms. This notion of

using the tactile and auditory in conjunction to essentially conjure up visual images in the mind of the observer will be an interesting avenue of exploration from a composer's standpoint and a perceptual rollercoaster from an observer's standpoint.

8 Tactile composition and emotion

This paper has thus far presented a substantial amount of psychophysical and physiological evidence in support of the feasibility of tactile composition, affirmatively answering the question: Is the human haptic system capable of processing / understanding tactile composition? What about the affective response to tactile composition? Music is widely considered to be the quintessential language of emotion. In light of the close coupling of tactile composition with music, two questions arise. First, how will the addition of a tactile component to the music listening experience influence the already existing emotional response to music? Second, how will exclusively tactile composition, without the music, fare as an emotional medium?

There is not yet an experiential or historical basis for an informed analysis of the affective response to composed tactile stimulation. This chapter highlights several factors that might be involved in this affective response, considering relevant theories and studies on music, tactile sensation, and affect. First we take a brief look at the relationship of the sense of touch with human emotions. Then we examine the nature of music as an emotional medium and subsequently think about what kinds of affective responses will be associated with tactile composition. Once the field has been established and there is a significant body of compositions - and a substantial audience for them - it will be very interesting to undertake systematic study of the affective response.

8.1 Touch and emotion

Montagu explains that although touch is not itself an emotion, its sensory elements induce those neural, glandular, muscular, and mental changes which in combination we call an emotion. Hence touch is not experienced as a simple physical modality, as sensation, but affectively, as emotion (1971). The reader is invited to think about the connotations of the word *touch* in the English language. Montagu gives several examples. When we speak of *being touched*, especially by some act of beauty or sympathy, it is the state of being emotionally moved that we wish to describe. The verb *to touch* comes to mean to be sensitive to human feeling. To be *touchy* means to be oversensitive and so on (1971).

Frank speaks of tactuality as an organic need during the infancy of a child. This tactuality, he believes, is gradually transformed as the child learns to accept mother's voice as a surrogate, her reassuring words and tones of voice giving him an equivalent for his close physical contacts, or her angry scolding voice serving as punishment and making him cry as if hit. Caressing becomes the chief form of intimacy and expression of affection with appropriate words and tones of voice. Thus all physical contacts become meaningful and colored by emotion (Montagu, 1971). The kind of tactile stimulation under discussion is that generated by human contact. Starting in the earliest days of infancy, we develop different emotional reactions to different kinds of human touch. Human touch is something that, unlike the human voice which can be recorded and played back with little degradation, cannot yet be replicated by technological means. The relationship of touch in the form of human contact and emotion is in a sense loaded; there are a number of factors that come into play in addition to the resulting cutaneous sensation on the skin. Taking these factors into account, we must approach the relationship of touch and emotion differently when the touching is being done by a machine, as in the case of tactile composition.

The skin's relationship with emotion is a two-way street. Not only does it serve as an input for the arousal of emotion, but it can reflect a person's emotional state. Emotional changes may be measured at the skin surface in a variety of ways, one of which is the psychogalvanometer or, as it is commonly mislabeled, "the lie detector." Emotional changes acting through the autonomic nervous system usually produce an increase in the electrical conductance of the skin across the palms of the hands or feet (Montagu, 1971). Such physiological signals may be used as crude indicators of a person's emotional state at any given instant. The Affective Computing Group at the MIT Media Laboratory built a wearable "DJ" that not only attempts to select music from performers that are preferred by the user, but also attempts to adjust its selection based on the feature of the user's mood (Picard, 2000). The system bases its decisions on the skin conductivity of the wearer, which tends to be higher while listening to more energizing songs and lower for relatively calming selections. From prior listening, it can watch which songs the user

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prefers to listen to when calm or active and which tend to calm or pep up the user more. The physiological channels through which music can elicit an affective response are discussed further below.

8.2 The affective response to music

All forms of art are thought of as involving some kind or degree of emotion either through direct arousal or though indirect representation. In this regard, music is often assigned first place (Pratt, 1950). Schopenhauer articulates this eloquently in his treatise on art (Pratt, 1950):

Music stands quite alone. It is cut off from all the other arts. It does not express a particular and definite joy, sorrow, anguish, delight, or mood of peace, but joy, sorrow, anguish, delight, peace of mind themselves, in the abstract, in their essential nature, without accessories, and therefore without their customary motives. Yet it enables us to grasp and share them in their full quintessence.

We will leave a debate on the true emotional nature of music to the philosophers. Here we are concerned more with, often used synonymously with the idea of emotion, the *affective response* to music. An affective response is one in which the stimulus has made some definite change in the organism. In many cases these responses can be measured as physiological changes; in other cases, the observable feeling reactions are so subtle and difficult to measure directly that we must simply depend on the introspective reports of the subject (Lundin, 1967). Efforts have been underway for over a century to uncover the details of our affective response to music. The general experimental approach often taken toward this goal is to isolate various features of musical patterns and determine whether they produce consistent emotional effects in the subject, as well as across subjects.

Although to this day, no definitive conclusions have been reached, scores of studies have found a correlation between various musical features and their resulting emotional effects on the listener. For example, in a study by Banks (1980), the emotional impact of several components of music were examined both alone and in interaction with each other. Changes in different features of the music - including tempo, instrumentation, meter and mode - were found to result in changes in specific response groups. In addition to the influence of individual components in music, several interactions among those components and context were found to be important in explaining emotional responses to music.

Lundin purports that upon examining some of the studies demonstrating various physiological reactions in music, one will find agreement on one point - that music does give rise to changes in the rate of physiological reactions including respiratory, cardiac, and blood pressure changes. One of the earliest studies, reported by Gamble and Foster, showed that loud music tended to have more effect on accelerating breathing rate and decreasing regularity, while soft music tended to increase regularity (1967). Weld (1912) found that when musical compositions were played, there was a tendency for cardiac activity to increase, and changes in the distribution of blood supply were observed. As mentioned above, music also has the effect of altering the conductivity of the listener's skin. The *galvanic skin response*, as it is called, is due to depolarization of the cell membranes of the skin through the action of the sweat glands, which are mediated by the sympathetic division of the autonomic nervous system (Lundin, 1967).

A study by Dreher in which both galvanic responses and verbal reports were recorded for various subjects during music listening showed that musically trained subjects exhibited a relationship between affective mood (as expressed by checked words on an adjective circle) and the galvanic skin response. This did not hold true for the musically untrained subjects, though. These findings support the belief that affective reactions to music, like all other musical reactions, are learned behaviors acquired throughout an individual's life history of interaction with the stimuli (Lundin, 1967). This result does seem intuitive. At the same time, as Mursell points out, although the musical apprehensions of the highly trained or intelligent are doubtless different from those of the untrained (or 'less gifted' as he puts it), the basic appeal of music is more primitive either than the factors primarily emphasized in music educations or than general intelligence (1937). Because of its holistic nature, even the most complex music can be readily appreciated without musical training or a high I.Q.

Gentile explains that the ecological approach to understanding how listeners detect emotion in music emphasizes the role of information in the music that specifies emotion. Adherents to the more traditional approach predict that listeners will not be able to judge emotion in music consistently until they have had a great deal of experience with music (1998). Gentile describes six studies with adults, preschool children, and eight-monthold infants that show that the ecological approach provides a more parsimonious framework for understanding the judgment and discrimination of emotion in music (1998).

The idea of kinesthetic anticipation, addressed in section 7.3, also ties into our emotional response to music. Mursell asserts that there can be no reasonable doubt whatsoever that these striking and universal kinesthetic effects constitute one of the most important factors of emotional differentiation among tonal-rhythmic patterns. The rising, the falling, the leaping, the smooth flowing, the hesitation, the resolving of the tonal organization dramatizes itself directly in our organic processes and compels in us differing ways of feeling (1937). In support of this view, it is found that an emotional response will take anywhere from three to fifteen seconds to establish itself after the impact of the stimulus; long compared to the latency of muscular reflexes. So we react with movement to a situation quite appreciably sooner than we react with feeling (Mursell, 1937). Jourdain goes even further to propose a physiological channel for the influence of bodily motion on emotion, suggesting that our bodily representations of music may be responsible for boosting our pleasure all the more by causing our brains to produce endorphins (1997). He describes a study in which Naloxone, an endorphin blocker, was administered to a group of music listeners. The results showed that those who received the blocker reported a substantially reduced pleasure in the music they heard while the control group, who received a placebo, experienced all the usual musical thrills.

The problem of emotion and music may also be approached by examining higher-level musical structures and patterns. Jourdain's account of the emotional response is that music sets up anticipations and then satisfies them. It can withhold its resolutions, and

heighten anticipation by doing so, then to satisfy the anticipation in a great gush of resolution (1997). The notion of expectancy – of anticipation, suspension, and resolution – is widely addressed in literature on the psychology of music, and certainly contributes to our understanding of the relationship between music and emotions.

8.3 The Affective response to tactile composition

According to Pratt (1952), if an emotion is to be real, the organs of the body, and in particular the viscera, must be made to vibrate. In the case of tactile composition, we literally bring the composition *onto* the body. At times, the tactile component of the composition might even feel as if it is originating within the viscera, rising up from beneath the skin. So the question arises: Can we intensify the a priori emotional response to music by adding an explicit tactile element? Intuitively, and from the author's personal experience, the answer is a resounding 'yes!'. The sense of immersion experienced with a tactile element coupled to the music is truly extraordinary. Music that is already capable of intense intellectual and corporeal stimulation gains new life, literally engulfing the listener. Granted, a lack of experience and experimentation precludes any solid apprehension of the nature of the emotional response to tactile composition, we will proceed to consider some of the possible mechanisms by which a tactile composition can evoke this emotional response. Please note that the following discussion makes a distinction between the affective response to simultaneous musical and tactile stimulation and the affective response to composed tactile stimulation alone. The combined response to tactile and musical stimulation is considered first.

An investigation of affective response is only complicated by the simultaneous presentation of information in two sensory modalities. However, to fully account for the emotional potential of a synesthetic medium, it seems necessary to consider the associated interactions between modalities. We've already addressed some of the intersensory interactions that might occur during the experience of a tactile composition. It would seem that the class of percepts resulting from various cross-modal interactions would have the capacity for eliciting their own emotional response, specifically by way

of amplifying and expanding upon those features of music which are so often attributed to experience of emotion.

In a study of musical enjoyment, Weld (1912) found that whenever visual imagery is present during listening, it is always *movement* imagery. Mainwaring (1933) has shown that kinesthetic imagery, that is, the feel of singing or playing or imitating the melodic flow, is essential in musical memory. Mursell (1937) suggests that there is good reason to believe that even among trained musicians pure auditory imagery devoid of kinaesthetic elements is comparatively rare. Jourdain (1997) proposes that certain musical statements are built from a "language" of physical movement, in which sonic objects move together in time, much as body parts move together as we navigate the world. Although this tendency to associate music with motion seems very natural and obvious, given the inherent temporal nature of music, it is nonetheless an important factor in the emotional response. By engaging the skin with composed vibrotactile stimulation, the figments of motion we previously experienced when listening to music are materialized and made tangible. In this way, the job of the tactile composer is to manifest his kinesthetic interpretation of a piece of music in a tactile form. With regard to motion, a tactile composition possesses expressive power very similar to that of dance; the essential difference being that dance is motion for the eye of the beholder and tactile composition, motion for the skin.

Pratt believes that for most listeners music makes an appeal to the mind, not to the body. The good lover of music, she claims, may derive keen pleasure from the last movement of Tchaikovsky's Fifth whereas if his body were involved he might find that movement an ordeal to be sweated out to the last dying gasps of the bass viols. The involvement of the body in music listening was speculated in section 7.3. While perhaps not as dramatic as portrayed by Pratt, the kinesthetic response may very well play some role in the music listening experience. Mursell (1937) believes that the kinesthetic response to music lends massiveness and potency to the musical pattern. There appears to be consensus, that, to some degree, the corporeal elements of the music listening experience have something to do with the emotional response to music.

One factor bearing on the kinesthetic response is the notion of muscular reflexes being activated in response to superficially presented vibrotactile stimuli. Granted, further experimentation is required to accurately determine the relationship between vibrotactile stimulation and muscle reflexes, through intricately composed tactile stimulation we might be able to, in a subtle sense, direct and influence the preexistent kinesthetic response to music. Under the speculation that this kinesthetic response is tied to the emotional response, we may thus be able to - albeit indirectly - influence the formation of emotions in the listener through composed tactile stimulations. Furthermore, composed tactile stimulation appears to have a definite kinesthetic response of its own. The author has collected some anecdotal evidence in support of this hypothesis. After experiencing some short tactile compositions using the Skinscape system, a colleague removed a transducer from each arm and slid them onto his ankles. His immediate reaction to the composition was to rhythmically move his leg. He subsequently commented that he felt a strong compulsion to dance. In general, the reaction of a significant number of people upon experiencing a tactile composition for the first time is to move their limbs. It makes complete sense that tactile stimulation should result in a strong kinesthetic response. The tactile, proprioceptive, and kinesthetic senses form a physiological system collectively referred to as the haptic system; and this system is tightly coupled with those parts of the nervous system dealing with motor control.

The natural links existing in our minds between sounds and tactile properties was discussed in Section 7.4. There is reason to believe, as Pratt (1931) and others have asserted, that in the varied range of tactile values which attach to tones we have a factor which produces affective differentiation. In researching "the psychology of pleasantness" in the 1930s, Beebe Center (1932), found pleasantness closely associated with "bright pressure" and unpleasantness with "dull pressure." That is to say, the introspective method would seem to indicate that the content of consciousness during the experience of pleasantness is dominated by the impression of bright pressure, and the impression of dull pressure. If we can accept these findings they would certainly indicate

that a differentiation of tactile values is likely to be influential upon affective and emotional conditions (Mursell, 1937). Based on this admittedly speculative proposition, certain tactile stimuli might inherently evoke certain emotions, just as various features of music are believed to do. By manifesting the tactile qualities of sounds on the skin during music listening, it may be possible to reinforce and amplify the influence of these sonic-tactile values on the affective response of the listener.

One study (Bassel and Schiff, 2000) provides direct evidence for a connection between vibrotactile stimulation and emotional experience. The experiment involved the administering of 24 minutes of unilateral vibrotactile stimulation to the left or right ventral forearm of subjects. Participants who received right-side stimulation persisted more in attempting to solve insoluble puzzles and made more positive judgments about an emotionally neutral film compared to participants who received left-side stimulation. The authors explain these emotional biases in cognition and performance with reference to the activation of structures involved in the processing of emotion specified in the Valence Hypothesis¹⁸. This result represents a step toward understanding the relationship, at a fundamental physiological and behavioral level, between vibrotactile stimulation and the experiencing of emotions.

Given that composed tactile stimulations have the capability to stir their own emotional response in the listener (this assumption is discussed below), we can proceed to think about the notion of interplay between the sonic and somatic emotional reactions. The most obvious use of the tactile component with respect to affect, is to reinforce or amplify the emotional response already induced by the music. In the case of certain approaches to tactile composition, namely those where the musical and tactile components are highly correlated, reinforcement and amplification of the musical emotional response by the tactile component seems a natural and expected result.

¹⁸ The Valence hypothesis contends that in right-handed individuals, the anterior region of the left cerebral hemisphere is associated with the ability to experience positive (approach-related) emotions, while the anterior region of the right hemisphere has been associated with the hability to experience negative (withdrawl-related) emotions (Bassel and Schiff, 2000).

Consequently, the coincidence of the two emotional responses has much potential to enhance the music listening experience.

Looking ahead into the not yet formed universe of tactile compositional devices, an alternative hovers: A composer might actually intend to create "dissonance" between the sonic and somatic emotional responses. An example of this idea is found in the history of visual music. Starting from the fact that his synesthesia had an emotional basis that intensified his experience of music, the composer Scriabin explored the artistic possibilities of the simulataneous playing of colors and music (Peacock, 1985). His piece Prometheus was written for two types of instruments: the musical instruments of the orchestra on one hand, and the 'tastiera per luce', a type of color-organ, on the other. He wrote a score for the tastiera per luce, that contained two elementary lines: one supporting the musical lines and one opposing them. The public was meant to hear consonance and dissonance in the movements of color and music. Scriabin's aim was to experiment with the emotional mechanisms of simultaneous auditory and visual perceptions (Campen, 1997). A consideration of such past efforts will undoubtedly benefit any future investigation of the emotional mechanisms of tactile composition. A compositional exploration of cross-modal emotional interplay is left to the tactile composers, but just imagine the compositional power that comes with the ability to instigate competing emotional reactions across modalities!

8.4 Exclusively tactile composition and emotion

When we remove the music, how will an exclusively tactile composition stand with regard to emotion? The notions of reinforcement and amplification are obviously no longer applicable. Can composed tactile stimulation alone evoke an emotional response in the observer? The author once again believes the answer to clearly be 'yes!'. Again, validation or nullification of this hypothesis can only come from practical experience with tactile composition. We now proceed to think about how an exclusively tactile composition might elicit an emotional response.

Tactile composition embodies some of those features of music attributed to the emotional response. Although tonal and harmonic structures do not translate very well to tactile composition, the rhythmic and intensive elements certainly do. Thus it seems intuitive that when these features, in their tactile manifestations, become recognizable and appreciable to the common observer, they will have a similar influence on the affective response as they do in a musical context. For instance, there appears to be some emotional quality associated with the envelope and duration of tactile stimuli. We would expect that most people are able to affectively differentiate a rapid attack, short duration stimulus from one with a more gradual attack and longer duration. As previously mentioned, different kinds of physical contact with other human beings are heavily colored with emotional associations; love and warm embrace, anger and abrasiveness, nervousness and incessant tapping, etc. These types of associations are of course influenced by additional non-tactile, human-related factors which are not present in the case of artificial tactile stimulation. Still, one could see how these associations would naturally translate to a tactile composition context. In light of the above, an exclusively tactile composition should be expected to have a primitive emotional appeal similar to that of music.

Perhaps the following exercise will elucidate these ideas. The reader is asked to imagine the sensation experienced from the presentation of two different tactile patterns to the skin. First, imagine a gentle wave of fluttery vibration that ascends smoothly up the right arm, undulates atop the shoulders for several seconds, and then smoothly descends down the left arm, disappearing into the wrist. What emotions do you primarily associate with this tactile image? Allow a few seconds to clear the cutaneous palate. Now imagine a jagged, intense low-frequnecy vibrotactile burst to the lower back, followed by an erratic swarm of sharp jabs to the arms. Compare the emotions evoked by this tactile image to the previous one. Is there a difference? If there is, as one might expect, then you have just affectively differentiated two tactile patterns. One can argue that the above descriptions are loaded with emotionally charged terms like gentle, fluttery, smooth, sharp, swarm, and jagged, but the fact of the matter is that these are the kinds of words we tend to use when giving qualitative report of vibrotactile stimuli. So, in a sense, this

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simple exercise of the imagination doubly illustrates the emotional qualities inherent to certain features of tactile stimulation.

While tactile composition does not have an extensive harmonic universe to work with, it does have space; and with space comes the potential for motion. By motion, we mean perceived physical motion (to be technical, in the case of the Skinscape system, *apparent* motion) on the surface of the body. The psychological phenomena of musical anticipation, tension, and resolution, apply equally to our perception of motion - any experienced dancer can attest to this. With the idea of tactile motion in mind, the tactile composer may approach the compositional process in a manner analogous to that of a choreographer. Extending an analogy made earlier in this manuscript, the tactile composer is essentially a choreographer for the skin. In any case, the emotive elements of motion are primitive and powerful, giving tactile composition yet another channel for the evocation of emotion.

Some of the ways in which tactile composition might evoke an emotional response have been enumerated. This discussion just begins, however, to scratch the surface of the affective response to tactile composition. Further elucidation and articulation of concepts relating to this topic will be facilitated by the growth and development of the field of tactile composition, specifically by widespread compositional activity and the establishment of venues for experiencing tactile composition. While some of the ideas put forth in this chapter are of a speculative nature, the author hopes that the reader is at least beginning to consider the emotional potential of tactile composition.

9 Exclusively tactile composition?

The vision of tactile composition was conceived in the author's head as a multi-modal activity. The idea originally arose out of thinking about how the field of music could be expanded in a new direction. What happens, though, when we shut off the music? Can a tactile composition engage the skin with the same intensity and power that music does the ears? For one thing, the sheer immersiveness of the experience is reduced with the removal of one or the other component. In particular, many of the cross-modal interactions between the senses are lost, reducing the overall perceptual richness of the composition. There is still much to be said and explored, however, about tactile composition in its own right. Our sense of touch is, after all, the first to form during our development in the womb and thus, in the earliest stages of life, we were deeply tuned to rhythmic vibrations such as the beating of our mother's heart and the rocking motions of her walking.

Most people have had some form of contact with music throughout their development. Music is a pervasive element of virtually all cultures and, although the extent to which people can analyze and appreciate music may vary, most can make sense of music at a fundamental level. On the other hand, tactile composition is not something people have been exposed to during the developmental stages of their life, or in most cases, at all. We are used to the relatively course tactile stimulation we receive on a daily basis – for instance, clothes rubbing against various points on the skin, temperature changes, the natural elements, and the wide range of tactile sensations we experience through our hands in the process of handling various objects and pressing various buttons. The haptic system, however, is just not accustomed to processing the complex and structured stimulation found in tactile composition. To the first-time feeler of a tactile composition, the removal of the audio component is likely to result in some confusion. In this respect, the coupling of tactile stimulation with music will serve to facilitate the learning process and increase our general awareness of the astounding information processing abilities of the skin. The music in a sense reinforces the tactile patterns of a tactile composition, putting them in a rhythmic and compositional context for the naïve observer. After a "training" period with the two modalities presented together, it is expected that people

will become acclimated to more complex tactile stimulations and that their ability to make sense out of these stimulations and appreciate their finer aesthetic variations will increase.

The possibility of tactile composition to hold its own as a compositional medium hinges largely on its ability to imitate various features and functions of music. The potential for tactile stimulation to evoke an emotional response was examined in the preceding chapter. Music derives much of its artistic power from its strong ties with emotion. One might imagine that the ability to invoke an affective response would similarly imbue tactile composition with such power, subsequently lending significant credibility to the idea of exclusively tactile composition. As proposed in Chapter Five, a number of parallels can be drawn between the vibrations that make up music and those that comprise tactile composition. From a compositional standpoint, music provides a very strong analogy with which people are already familiar. Accordingly, analogies from music will help to jumpstart the piecing together of higher- level forms and compositional techniques for the tactile modality.

Another factor influencing the feasibility of exclusively tactile composition is complexity. Even the most seemingly simple music involves some fairly complex manipulations of sound. In order to successfully hold the observer's interest, it seems necessary for a tactile composition to exhibit a certain level of complexity. We have identified a number of basic vocabulary elements for the vibrotactile sense that can be manipulated and combined to form more complex compositional structures. Based on the wide range of tactile responses comprising our sense of touch, one might argue that by engaging only the vibrotactile response, we do not even come close to the amount of complexity the skin can handle. In response to this argument, the advent of more comprehensive tactile stimulators capable of simulating the full spectrum of tactile sensations will make tactile composition even more robust on its own. By pulling, pushing, stretching, vibrating, tapping, heating, cooling, and squeezing the feeler, the full potential of the sense of touch as a compositional medium may be realized. At the same time, after some very basic composition experiments using the Skinscape system, it became quickly evident that enough variation and complexity can be generated working with vibrotactile stimulation alone. Once again drawing an analogy to dance, dancers can and have danced to silence and successfully engaged their audience; presumably not to the extent that the synesthetic mixture of dance and music can, though. Nonetheless, the possibility of composing exclusively in the tactile modality should not be overlooked, for it can drive the evolution of tactile composition in many different and exciting directions.

10 Additional applications

The potential applications for a system which facilitates composition in the tactile modality are manifold. As suggested above, tactile composition has the potential to evoke a very powerful affective response, lending it to myriad situations in which it is desirable to introduce an element of emotion or enhance an already existing emotional response. This chapter considers several interesting applications for tactile composition.

10.1 Tactile accompaniment for dancers

A number of colleagues have suggested the possible use of the technology employed by the Skinscape system in a dance context. In one potential scenario, a dancer would wear the vibrotactile stimulator - in a wireless form of course - and essentially dance to a tactile composition. The audience would in turn receive the same tactile stimulation as the dancers, through their own personal stimulators. For the dancer, this silent vibrotactile accompaniment would represent a novel coupling of the tactile and proprioceptive/kinesthetic senses, perhaps motivating different types of movement and choreography. In addition, by reminding a dancer to move certain body parts at certain times, tactile cues might serve as a means of augmenting instructional techniques for dance education.

Alternatively, the tactile composition could be driven by the motions of the dancer. In this case, an array of motion sensors would interpret the dancer's motions and provide input to a computer algorithm which would subsequently map them to spatio-temporal tactile patterns on the surface of the body. The audience would in turn experience the tactile stimulation in conjunction with the visible movements of the dancer.

10.2 Applications for the hearing impaired community

The notion of tactile composition opens up many avenues of exploration for the hearing impaired community. The experience of music for deaf individuals is generally limited to coarse, low-frequency physical vibrations. By introducing an intricate tactile component to the music listening experience, in particular one that is closely correlated with the underlying music, we are able to convey a significant amount of the detailed

structure of the music to deaf individuals. To a deaf person, who is likely to be very accustomed to receiving information through vibrations, the concept of tactile composition should represent a natural extension of music. In fact, once the underlying musical element is removed and the composition occurs exclusively in the tactile modality, tactile composition will represent an artform that people with normal and impaired hearing could appreciate alike.

One interesting application related to the hearing impaired community is the tactile equivalent of a closed captioning system for television. A *tactile captioning* system could serve as an additional channel through which various sonic and other more abstract features of a television program might be conveyed. Alternatively, the tactile track can be used in a more literal manner, similar to tactile speech communication devices such as the Tactaid (see Appendix B for more information). If the vibrotactile stimulator for such a system was widely distributed across the surface of the body, as in the case of the Skinscape stimulator, spatial information about a scene - which current text-based captions cannot convey - may be encoded. More generally, a tactile captioning system could benefit individuals with normal hearing by helping to reinforce the ambient sounds in a scene, distinguishing them from the external ambient sounds of the room where the television resides.

A tactile composition system might also serve as a means of musical feedback for deaf musicians. Musicians who lack the sense of hearing – the most well-known example being Beethoven - often utilize the mechanical vibrations produced by sound to musically orient themselves. Although many deaf musicians, through sensory substitution, have developed an acute sense of touch and can receive an astounding amount of information from such physical vibrations, such vibrations are generally coarse and provide a limited amount of musical information. A system like Skinscape might be used to map intricate rhythmic, intensive, spatial, and even harmonic musical features onto the skin to give the deaf musician an enhanced sense of musical orientation. Even an 'instrument-to-place' mapping scheme where the sonic outputs of the instruments of an ensemble are routed to separated points on the skin, might prove highly useful for a deaf musician.

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10.3 Algorithmically-driven tactile composition

Imagine the following scenario. You sit down at your desk, slip on your full body vibrotactile stimulator, pop your favorite CD in the stereo, and press play. You then sit back and close your eyes as a cutaneous dance unfolds along with the music on your skin. The conception of tactile composition as presented in this paper is just what it sounds like in that compositional decisions are made by human minds and human hands. With the advent of computers came algorithms that could, in a limited sense of the word, do the composing for us. Take, for example, the wide variety of music visualization programs available, often in the form of plugins for software media players such as Winamp. These programs extract some basic features from the music using techniques such as beat detection and frequency spectrum analysis and subsequently use this information to control some pre-composed visual pattern. Using the same techniques, we can drive tactile patterns. The innate challenge with such algorithmically driven choreography, regardless of modality, is to do something compositionally interesting with the extracted information. A variety of tactile patterns can be made to dance atop the skin in response to a piece of music, but will the resulting experience hold the observer's attention and be aesthetically pleasing? Another application for algorithmic tactile composition is as a musical transcription tool. By reinforcing both temporal and intensive features of the music such as rhythmic structures and intensity envelopes, it might be possible to enhance performance in transcription tasks. Along these lines, a tactile component may even be used to train people to listen to complex music, specifically by 'picking out' certain features and reinforcing them in the tactile domain to draw the listener's attention to them 19 .

10.4 The medicinal benefits of vibration

Vibrations have been found to possess various medicinal qualities. In fact there is a field of alternative medicine built around vibration. The Einsteinian viewpoint of vibrational medicine sees the human being as a multidimentional organism made up of physical/cellular systems in dynamic interplay with complex regulatory energetic fields.

¹⁹ O'Modhrain, Sile. Personal communication 2/01

Vibrational medicine attempts to heal illness by manipulating these subtle energy fields via directing energy into the body instead of manipulating the cells and organs through drugs or surgery. Two direct physiological benefits of vibrotactile stimulation are the facilitation of bloodflow and the relaxation of muscles. The class of commercially available gadgets referred to as 'personal massage devices' work on this principal of muscle relaxation. Anyone who owns one (or has picked one up in a high-tech gadget store and played with it) can attest to the therapeutic effects of vibration. In recent years, there has also been some interest in the use of musical vibrations for mentally disabled, specifically autistic, children. One commercially available product, called Soundbed (see Appendix B for more information), is a resonant box into which music is played. The vibrations of the music are mechanically coupled to the body of a person who rests atop the box. Most of us have at one time or another, experienced the therapeutic effects of music. Music has the power to excite and increase the rate of various physiological processes in the listener, but equally it has the power to calm. Imagine the state of relaxation one could reach with the combined musical and vibrotactile stimulation of a tactile composition.

10.5 The future of movies

Movies are widely considered to be the quintessential synesthetic medium. You see the images unfolding on the screen, you hear the soundtrack, and nowadays with powerful surround sound systems such as THX, you might even feel the low-frequency vibrations of explosions. With the addition of a tactile element to the movie watching experience comes even more synesthetic power. In his visionary novel *Brave New World*, Aldous Huxley (1932) describes a high-tech form of entertainment called the *feelies* in which, by placing the hands on a set of knobs, a person can experience tactile sensations in conjunction with audio and video. In Bruce Wagner's novel *Wild Palms*, an interactive entertainment system capable of projecting realistic, moving holograms is augmented by an experimental underground drug which, when ingested, creates the illusion that one is being touched by the holograms. History has seen several efforts to incorporate a haptic element into movies. The theme park has been a primary venue for such efforts. One can watch a movie in which sharp puffs of air against the ankles coincide with the image

of a hundreds of mice on the screen. Other rides augment images of flight and movement with hydraulically controlled seats that manipulate the audience's proprioceptive sense. The aim of these and other efforts is the realistic simulation of a haptic scene. We might group these virtual-reality-like uses of haptics technology in the category of "literal applications of haptics". While such literal applications, especially in the case of cinema, are a step in the right direction toward an increasingly synesthetic experience, they are extremely limited by current technology. It was mentioned that there is no one device capable of generating the full range of tactile sensations and certainly there is no one device which can generate the full range of combined proprioceptive, kinesthetic, and tactile sensations.

Given the technology currently available though, there is much that can be accomplished along the lines of aesthetic or expressive composed tactile stimulation in conjunction with a medium such as the movie. To strengthen the dichotomy between literal and aesthetic applications of haptics, a distinction is now made betwen what we will call *tactile sound* effects and a tactile soundtrack. Sound effects are used in movies to increase the realism of movement and action sequences on the screen. Analagously, tactile sound effects constitute those haptic stimulations coupled to the action of the movie which serve to enhance the realness of a scene and draw the audience into this action. Alternatively, the soundtrack of a movie is essentially used to direct and/or amplify the audience's emotional response to the movie. It is in this capacity, that of a tactile soundtrack, that a tactile component coupled to a movie would seem have the most dramatic effects, given the current state of technology. One simple idea would be to loosely correlate this tactile soundtrack with the level of action in any given scene in the movie. This might be accomplished by using the instantaneous RGB values of a movie to algorithmically control the tactile stimulation. Even simpler, a tactile track could be composed as an accompaniment to the preexisting audio soundtrack, with the effect of reinforcing and amplifying the emotional response intended with the audio alone.

Another promising area of exploration is parallel, multimedia composition in the visual, auditory, and tactile modalities. In this way, we may unlock the power of visual cues for

'cognitively twisting' the perception of a simple tactile pattern. This might entail various spatial mappings from the field of vision to the field of touch (namely the skin). When thinking about tactile stimulation and cinema, an interesting issue results from the egocentric nature of our sense of touch. Using a tactile component, we may be able to shift the audience's perspective from character to character in a way we cannot, using visual and auditory feedback alone. This may represent a very useful compositional tool for movie makers. In any case, the compositional potential realizable with the simultaneous engagement of three senses is extraordinary.

10.6 Tactile composition as "background music"

The observations of several colleagues who have experienced the a composition on Skinscape without the music seem to indicate that composed vibrotactile stimulation of the skin is not as distracting as music listening. This may be partly because we are not accustomed to processing such intricate vibrotactile stimulation and thus do not direct our full attention to it. This consideration aside, vibrotactile stimulation does generally appear to be less intrusive on our concentration than music. Under this assumption, a tactile composition might be useful in situations where a person needs to maintain a certain level of concentration and cannot do so with music playing. For instance, a system which could play tactile compositions would be of much use to college students who need to stay awake (and maintain their sanity) but either can't focus with music on or don't want to disturb their neighbors with loud music. Playing a tactile composition in the background of one's haptic scene could have a relaxing effect similar to that of music, keeping the person energized, but not so distracted as to cause a loss of concentration.

11 Topics for further exploration

11.1 The impact of cultural differences

There is much variability across cultures and societies in the way that the sense of touch is viewed. Frank explains that each culture fosters or specifically trains its young as children and as adolescents to develop different kinds of thresholds to tactile contacts and stimulation so that their organic, constitutional, temperamental characteristics are accentuated or reduced (Montagu, 1971). Without going deep into psychological or anthropological theory, the emotions evoked by a tactile composition are likely to exhibit some degree of cultural dependence. We see this with music, where a composition can be fully understood in the context of its culture and assumes a different place in the musical spectrum among different cultures. It will be interesting to see how such differences in cultural perspectives on touch will manifest themselves in the affective response to tactile compositions.

It has been observed that the attention paid to the skin varies across different cultures of people. Montagu (1971) writes that one of the consequences of the habit of wearing clothes from early infancy is that the skin fails to develop the sensitivity it would have done had clothes not been habitually worn. It has been observed, for example, that among nonliterate peoples the skin is very much more responsive to stimuli than it is among Europeans. Kilton Stewart in his book, Pygmies and Dream Giants, reports of the Phillipine Negritos that they "are very sensitive to creeping things, and were amazed that an ant could crawl up my leg without my being aware of it" (Montagu, 1971). This difference would, in the least, be a factor in a culture's overall acceptance and enjoyment of composed artificial tactile stimulation.

Society's collective views on the sense of touch will have some bearing on the acceptance of tactile composition. Tactile stimulation is typically initiated by the person who experiences the resulting sensation, i.e. to feel the texture of an object, one might run his or her finger along the surface of the object. The idea of receiving uninitiated tactile stimuli - in a sense, being bombarded - is something that we are not used nor do we readily welcome. Furthermore, we are not accustomed to receiving tactile stimuli

generated by a mechanical, non-living entity. Granted, during the past century, the idea of "personal massage devices" which create vibrations against the skin has become more widely acceptable in certain cultures, these devices are generally manipulated by the person who experiences the resulting sensations. True, with the advent of recorded and amplified music, we have become very accustomed to the reception of audio stimuli generated by electro-mechanical devices such as speakers. However, direct physical contact is not required to create a sensory response in the auditory system and hence music does not invade our personal space. Much of this boils down to a fundamental tenet ingrained in our minds, articulated by Aristotle circa 350 B.C.: *What can touch you can hurt you.* Consequent to the above factors, the idea of strapping on a device which produces vibrating, crawling, writhing, tapping (to name a few) sensations against the skin might not be well received by some people.

11.2 The implications of multi-modal composition

In the formulation of tactile composition presented in this paper, the tactile is basically subservient to the music; the composer chooses a piece of music he wishes to choreograph and then proceeds to compose the tactile component. Because the music is already set in stone, it is not affected by the tactile composition process. We now briefly consider the possibilities of multi-modal composition, i.e. composing in parallel in the sonic and tactile domains. There is much territory to be explored in terms of the interplay between the respective composition processes. For one, a world of cross-modal phenomena become available to the composer working simultaneously in two modalities.

Sociologically speaking we live in a world dominated by visual imagery (Laske, 1976). Compositionally speaking, to a certain extent, we might say the same. It seems safe to say that the majority of music compositional activity is driven in the minds of composers by, foremost, auditory and second, visual imagery. Over the past century there have been several movements in music revolving around texture and timbre, using these properties as organizing principles for composition. However, it is one thing to talk about the texture of a sound using touch-related adjectives, but a whole different thing to talk and think about such textures in a truly tactile context, imagining how they would feel against the skin.

Galeyev believes that synesthesia is an essential sign of artistic thinking for all kinds of art, including music (1993). When composers start to pay more attention to the sense of touch and begin to form sonic-tactile associations through experimentation with tactile composition, how will the way they approach music composition be affected? How will *tactile images* be used at a cognitive level in the mind music composer? How will they interact with auditory and visual images to drive composition? In general, what are the implications of tactile composition for music and other more traditional compositional mediums?

11.3 Research and experimentation

There are two ways experimentation with tactile composition can be approached. In the first type of approach, psychophysical experiments are conducted to test the haptic system's ability to detect, discriminate, and perceive various stimuli. This 'bottom-up' kind of approach is valuable for informing the formation of compositional building blocks. There is a large body of psychophysical research on the auditory system aimed at understanding our perception of music. The paradigms and approaches used in this field might be applied in experimentation with tactile composition.

Verrillo and Gescheider explain that when the problem of cutaneous temporal relations is investigated for complex displays in which many areas of the skin are stimulated in various temporal sequences, cognitive factors such as short-term memory, attention and pattern recognition become increasingly important. Advances in our understanding of these complex cognitive processes as they relate to tactile perception should correlate with significant improvements in tactile communication systems (1992). Such advances in understanding will likewise have an impact on tactile composition. One specific area that has not received significant attention in the literature is cross-modal interactions between audition and touch. Tactile composition has much to gain from an understanding of such interactions. As we delve deeper into the field of tactile composition, it is important to maintain an open line of communication between science, technology, and art. Campen discusses how, in the study of perceptual phenomena, scientists and artists have often used each other's discoveries to start new directions in their own disciplines (1997). In this way, artistic experimentation can contribute to new directions in psychophysics and perception research.

At the same time, tactile composition - much like music - is a holistic medium. Accordingly a 'top-down' kind of approach is also invaluable for understanding the synergistic sum of its parts. This includes exploration in the compositional process; as mentioned previously in this manuscript, the most useful insights into our perception of composed tactile stimulation will probably come from a working knowledge of tactile composition, which can only be built through compositional experience. To put it simply, experience allows one to find out what kinds of things work and what kinds of things don't. Pellegrino reminds that in exploring the multitudinous forms of the electronic arts it is essential to maintain the delicate balance between losing oneself in its infinite potential and becoming bogged down in analysis and measurement. Observation, intuition, reflection, and the experiential mode of learning, he believes, are the keys to any exploratory process, including that of electronic arts (1983).

12 Discussion / Conclusions

A primary goal of the present manuscript is to establish a foundation for the relatively uncharted field of tactile composition, but before doing so it was necessary to consider the feasibility of composing in the tactile modality. In the course of this paper, through theoretical as well as practical investigation, the feasibility of tactile composition has been affirmed. In addition, several theoretical issues were examined, resulting in as many questions as answers. These issues are far from being resolved and hopefully the questions arising in the course of this manuscript will excite and inspire others to search for answers. This search will be facilitated by the development of a set of tools for tactile composition. While Skinscape is a work in progress, it represents a first step toward this end.

After hearing a brief description of the Skinscape system, a friend of the author asked, "Does it feel cool?". This simple question, which might be paraphrased *Does the system produce aesthetically pleasing, perceptually engaging sensations?*, probes the fundamental success of the system with respect to its ability to generate tactile compositions. Due to time constraints, the composition interface for the system at the time of this writing is very basic and, in various respects, limiting. Composing with the system is a somewhat unintuitive and tedious process. Composition interface aside, the system is a great success from the observer's standpoint. Upon playing back his initial compositions, the author was extremely excited and surprised at the sheer immersiveness and expressive power of the system. It is also noted that these compositions were relatively simple and did not even begin to tap the more interesting concepts proposed in this paper.

With the availability of compositional tools, we can begin to experiment at a number of different levels. Experiments at the lowest level will contribute to the formation of elementary building blocks for composition as well as provide insight into the response of the human haptic system to abstract, aesthetically composed tactile stimulation. Following the completion of this thesis, the author plans to carry out several

psychophysical and perceptual studies along these lines. Experimentation at the highest level, namely through compositional activity, is of vital importance in establishing the field. It is this kind of experimentation that is driven by – and will further propel – the primitive human desire to engage in artistic creation. At a profound level, it was in fact the author's overriding hunger for musical and artistic experience that motivated the composition of the present manuscript. Pellegrino comments on the electronic arts of sound and light:

The electronic arts of sound and light are unquestionably in the sphere of the experimental arts and will probably remain so for some time to come. As such they involve extended periods of play and exploration, protocompositional stretches of the free flight of imagination. The opening play-phase is born of curiosity, a sense of wonder, and the confidence that the presently unfamiliar material has immense expressive potential. In a seemingly chaotic and fragmented fashion, one investigates the unfamiliar until it becomes familiar. Serendipitously one discovers significantly expressive forms that warrant further manipulation, extension, and testing (Pellegrino, 1983).

This excerpt eloquently captures the present outlook for tactile composition. With the first tools in place, we can now begin to explore the universe of composition in the tactile modality.




Appendix A (cont) Skinscape MAX/MSP code Multitrack recorder

Appendix B: Relevant prior arts

Below is a list of several existing tactile stimulation devices²⁰. These devices vary widely in complexity – from a simple resonant cavity to a computer-driven, multi-interface gaming system. The unifying characteristic of the systems presented below is some cross-modal translation from sound to touch.

Interactor Vest (Cushion and Bass Shaker) (Aura Systems, Inc.)

This product was released about four years ago, but never really caught on and was discontinued. It was aimed at a teenage audience and intended primarily for entertainment, i.e. as a tactile feedback device for videogames. However, it can be driven by any music source as well. The two main components are a back-pack like vest and an amplifier. The vest contains a 12" woofer which transfers vibrational energy to the flat face of the casing, which is coupled to the user's back. The case is made of solid plastic. The amplifier contains circuitry which divides all incoming frequencies by four so as to place them in the active frequency range of the woofer. The amplifier has two dials: one which controls the output level and another that basically controls the width of the filter. A cushion version of this device, which was used in the Skinscape system, was also released. Aura also manufactures a similar product called the Bass Shaker, which can be mounted on any chair and imparts low-frequency vibrations to the user's bottom.

Intensor Chair (BSG Labs)

The Intensor Chair imparts sonic vibrations to various parts of the body. It is intended for entertainment purposes and was designed with dual functionality in mind: both as a stereo system and as a tactile feedback device. The device contains a total of five speakers, plus an optional subwoofer (which sits apart from the chair). A large 5.25" full-range speaker is positioned in the crotch, with two smaller 2" full-range speakers on the outside of the thighs. There's another 2" tweeter behind the head, and the fifth is a 5.25" bass driver that is embedded in the back of the chair. The bass driver provides powerful tactile feedback straight into the back of the user. The Intensor game chair itself has two controls on it: a master volume control and a tactile intensity control, to adjust the amount of low-frequency feedback sent to the transducers. The subwoofer also incorporates its own volume and bass crossover controls. BSG Labs rates the chair up to 108 dB.

VRF's Tactile Feedback System

This system consists of a central control unit which takes in audio from any source and accordingly drives an (expandable) set of haptic and tactile feedback devices. The unit can be connected to the parallel port of a computer. The only currently available device for use with the system is a cushion containing 6 actuators; two are mounted on the back, two under the right thigh, and two under the left thigh. The actuators use heavy duty industrial brushless 26 volt Mabuchi DC motors. The unit can operate in one of two modes: Intellivibe and AudioSense.

²⁰ Note that the detail and level of abstraction at which each system is described varies due to the limited availability of technical documentation for some of the products.

In Intellivibe mode, the actuators are directly driven by signals coded into the game. This feature provides a direct control interface, which game developers can use to design their own tactile feedback. In AudioSense mode, the control unit uses an analog audio preamplifier and three analog audio frequency filters to amplify and separate the incoming audio signal into bass, midrange, and treble signals. The three signals are sampled at 400 Hz and independently processed by a set of configurable digital filters. There are 11 parameters associated with the processing of each frequency band, which can be configured by loading a special file onto the control unit from the computer.

Tactaid series (Audiological Engineering)

The Tactaid series of tactile hearing aids presents coded sound information via a set of vibrators resting on the skin. The vibrotactile stimulator consists of a linear array of V1220s (different models use different numbers of transducers) enclosed in a soft pouch that is typically worn on the forearm. The stimulator is controlled by a small electronic pack worn on the belt of the user, which divides incoming sound into frequency bands, applies various signal processing algorithms, and subsequently sends the separated signals to different vibrators. In this way, information can be transmitted through the vibrators in four different ways: (1) place of vibration, (2) movement of vibration, (3) strength of vibration, (4) duration of vibration. The coded vibratory patterns are unique, consistent and learnable, providing information on a range of speech characteristics, including: voice-voiceless sounds, inflection, intensity, temporal cues, and the crucial first two formants that assist in vowel recognition. The Tactaid devices have been found to significantly enhance lipreading performance in hearing impaired individuals and also serve to convey environmental sounds – such as a doorbell ringing or a baby crying – to the user.

Tactuator (MIT Research Lab for Electronics, Sensory Communications Group) The Tactuator was designed for research purposes – in particular the study of communication through the kinesthetic and vibrotactile aspects of the tactual sensory system of the hand. The display consists of three independent single contact-point actuators interfaced (individually) with the fingerpads of the thumb, the index finger, and the middle finger. It is unique among tactile communication devices in that it provides both haptic and tactile feedback. Stimuli from threshold to about 50 dB SL can be delivered over a frequency range from near DC to above 300 Hz, thereby encompassing the full perceptual range from gross motion to vibrations.

Sound Box

Sound Box (and Sound Bed) are wooden cabinets under which a set of speakers are placed facing upward. The cabinets resonate in response to sound waves from the speakers, imparting vibrations to the person resting atop them. These products have been adopted for use by deaf and autistic children, potentially as a means of therapy.

Brain Shaker (Panasonic)

The Brain Shaker is a wearable tactile stimulator. The device is essentially a pair of headphones, which wrap around the back of the wearer's neck. Mounted on the back of the neck is a small case containing an amplifier, a vibrational transducer, and some

additional processing circuitry which filters the incoming audio signal, boosts in in the 50 Hz range and then transforms the low frequency signals into vibrations against the neck. The device is, in a sense, a 'wearable sub-woofer.'

Sonic Stimulator (Auditac)

The Sonic stimulator uses amplified audio signals to drive an electroacoustic transducer, which directs the sound waves through a wave guide to a probe adapted to couple the sound directly the skin with minimal acoustic radiation. The inventor of the device envisioned it being used in a variety of applications including sensory substitution, the generation of 'body music,' pleasure stimulation, biopotential feedback, physiotherapy, and the generation of new media for new perceptions and as a part of multimedia experiences (Wachpress, 1975).

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