

Active Vision

Controlling Sound with Eye Movements

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Abstract

In this article, the author discusses the inspiration, concept, and technology behind her sound performance work using eye movements in relationship to current research on human eye movement. She also compares the playing of the eye-tracking instrument to research on musical improvisation using unconventional musical instruments and "active music."

Eye Movement

Non oculi tacuere tui.

Your eyes were not silent.

—Ovid [1].

Seeing is active. Vision cannot occur without finely tuned movements of the eye, taking in patterns of light and color on the retina which the mind must then translate into a coherent world. The demand for realistic computer simulations and accurate machine vision has sparked a renewed interest in human vision among researchers of many disciplines. I would like to discuss some of that research and how it relates to my own work with vision-tracking musical instruments.

Eye movements can be divided into three distinct types that are under voluntary control: *convergence*, *smooth pursuit*, and *saccades*. *Convergence* is the process of following objects as they approach or move away. Smooth eye movements keep the line of sight on a selected object and compensate for motion on the retina that might be caused by motion either of the object or of the head or body. In order to be initiated or sustained, *smooth pursuit* requires an external moving visual signal. The third type of movement, *saccades*, are those which interested me most for performance. These

movements are rapid jumps of the eye used to shift gaze to a chosen object. Once a saccadic movement has been initiated, the movement cannot be interfered with until it reaches completion [2].

Smooth eye movements and fixation occur in the intervals between saccades. Intervals between saccades can be as long as several seconds during steady fixation, and, in reading, about three times per second. Even when fixating, the eyes continue to move. They tend to drift and flick involuntarily and to oscillate back and forth continuously, although these movements are extremely small [3]. Sequences of fixation and saccades have been used to study cognitive processing in the coordination of eye and arm movements, during visual problem-solving tasks, and during reading [4].

An increase in the speed of saccades can be learned or taught with daily practice, and although saccades cannot be interrupted once they are initiated, many researchers indicate that saccades are planned, controllable activities. Some researchers suggest that shifting attention to another location while the eye remains stationary is the same as planning a saccadic eye movement. In other words, sequences of saccades and fixation are directly related to attention. Attention is allocated to a target shortly before the saccade is made to look at it [5].

Allocation of visual attention is related to the content and meaning of the subject. Saccadic eye movements in particular are used to inspect a visual scene, requiring the integration of discrete time frames into a stable picture of the scene. In 1967, A.L. Yarbus conducted a series of experiments in which recordings of eye movements made while looking at various paintings show systematic preferences in movements: the eyes would repeatedly look at those elements that would seem to be most relevant to the painting's content [6].

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The Language of the Eyes

*Think ye by gazing on each other's eyes
To multiply your lovely selves?*

—Percy Bysshe Shelley [7].

As an artist, one reason I became interested in using eye movements in my work was an increase in my use of computer-mediated communication systems for artistic collaboration. I found that the most commonly used of these systems lack the subtleties of eye movements and generally do not incorporate them at all in the system (e-mail and the telephone, for example). In contrast, I collaborated successfully on several occasions with artists with whom I did not even share the same language but could meet with in person.

Looking into scientific and cultural reasons for this phenomenon, I found a gap between vision science and popular culture. The movements of the eye hold a mysterious fascination, giving rise to the idea (or dream) that the code of eye movements, if deciphered, hold the key to the human psyche. Some pop psychology says that one can read specific meanings into specific directions of eye movements as a means of interpreting nonverbal communications, but this is unsubstantiated in the scientific research.

The gaze has also been associated with power. Symbolically the eye represents dominance: for example, the eye on top of the pyramid on the U.S. dollar and the eye as the sun in Chinese mythology. As a symbol of power, the eye often symbolizes a powerful evil: the belief in the evil eye exists worldwide [8]. Here the act of seeing is active and aggressive. In feminist theory the “male gaze” is also a threatening power, and art historian James Elkins discusses the dangerous nature of the lens which objectifies its subject: “This seeing is aggressive: it distorts what it looks at, and turns a person into an object in order to let us stare at it without feeling ashamed. Here seeing is not only possessing . . . seeing is also controlling and objectifying and denigrating. In short, it is an act of violence and it creates pain” [9].

The power of the gaze is even a part of the popular mythologies of everyday experience. Simon Baron-Cohen describes a common perception: “Imagine you walk into a crowded train. . . . During the jour-

ney, you become aware of a feeling that someone is looking at you. You glance along the carriage and, sure enough, someone is looking at you. As soon as you make eye contact with the stranger, he looks away. To my mind, this phenomenon is rather striking, in that it is not immediately obvious how you would have known that someone was looking at you, if you were already engaged in another activity” [10].

Depending on the context, eye contact can have any number of meanings attributed to it. Research on humans and animals has shown that eye contact causes an increase in heart rates and electrical activity deep in the brain stem [11]. Eye contact often occurs as a friendly signal or a signal for reconciliation, and it occurs with greater frequency between a mother and her child and between lovers. These unconscious factors may also be related to the culturally held belief that looking implies desire. In mythology, the story of Narcissus is based on the inextricable relationship of looking to desire. Elkins writes, “All seeing is heated. It must always involve force and desire and intent. Even when I think I am least interested, I am already on the prowl. It doesn't matter what I'm looking at—a watch, a shiny hook; ‘just looking’ is a lie. I am always looking out, looking for, even just looking around” [12].

All these factors have been linked to esthetic judgments in the history of art, as Christopher Tyler suggests in his work analyzing eye positioning in conventional portraiture [13]. He shows that a vast majority of conventional portraiture contains one eye that is central to the composition and looking directly at the viewer.

Seers Are Blind

Metaphorical connections like these between eye movements and meanings abound, as do metaphors linking the eye itself and the act of seeing to our technologi-

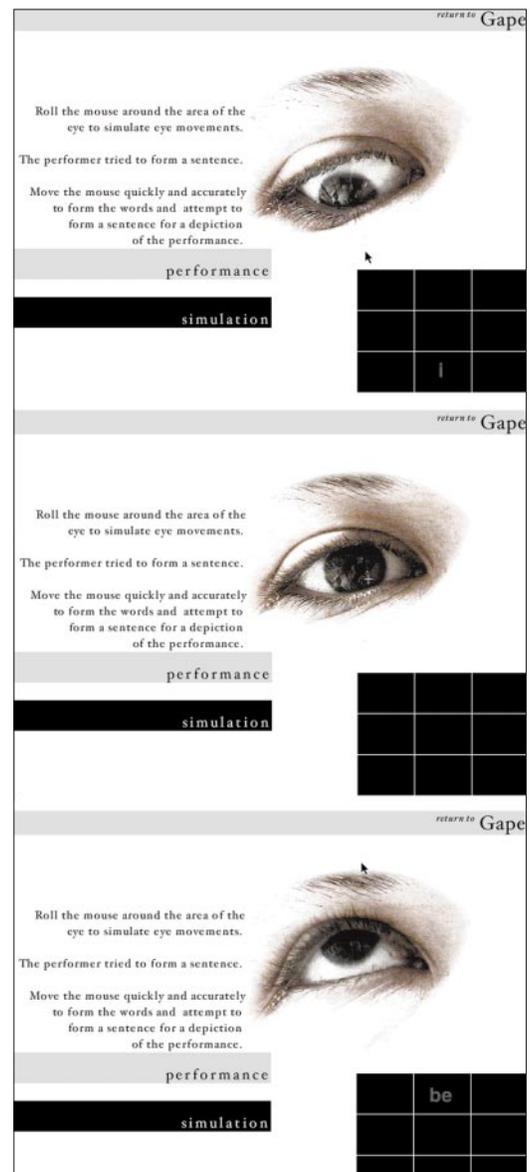


Fig.1. A sequence of screen shots from a CD-ROM demo of *Gape*. As the eye position changes, the word illuminated in the grid changes correspondingly. Images by courtesy of the author.

cal society. An ever-increasing barrage of rich images (often called “eye candy”) is a part of daily life for the modern urban citizen. Just as we constantly receive visual images, we constantly give images to a multitude of unblinking camera lenses which document our every transaction. The most widely used computer interface is called Windows, just as the eye has often been called a window.

One of the most intriguing metaphorical connections between the eye and the mind is Luciano da Fontoura Costa's suggestion that human cognition itself is structured along the lines of eye movements. He describes a metaphorical link between spe-

cific categories of eye movements and thought: “After pursuing some ideas for some time, our thoughts are directed somewhere else, into a new subject that is nonetheless associated in some way to what we were thinking before. If you close your eyes now, it is very likely that you will continue, for some time, thinking about the ideas presented in the last sentences. Then, you may start wondering about related ideas and concepts (‘smooth pursuit’), sometimes focusing on specific themes, sometimes moving to completely new ideas (‘saccades’)” [14].

Despite the visual dominance of contemporary culture, there is disagreement about which sense is actually dominant. There are three times as many nerve connections between the ear and the brain as between the eye and the brain, and humans have been shown to learn more through the ear than through the eye [15]. Symbolically, blindness, often associated with increased aural perceptive ability, is related to “inner seeing.” The legends of Homer and Oedipus are two of many examples. Diether Rudloff explains: “The eye is a peripheral sense because it is directed outwards and only comprehends the external person. The ear on the other hand is a central sense since the outer world enters the human soul through the ear, apprehending the concealed inner being. That can be demonstrated at any time in everyday experience since blind people are usually more inwardly sensitive, focused, and spiritual than those who can see” [16].

In my own history as an artist, I have sometimes imagined the computer to be a “disembodied mind.” This metaphor, created by early researchers of artificial intelligence, has moved into the mainstream. Although the widespread adoption of the “computer as mind” metaphor is limiting, such an idea might pave the way for an equal valuing of the senses. The idea of a “pure thought” outside of the filtering of the senses suggests “pure information,” which can be equally transmitted through visual, aural, or even tactile means. Josephson and Carpenter state that “aesthetic processes have a certain universality, making them essentially independent of the ordinary biological domain” [17].

Does this universality suggest esthetic

synesthesia? Metaphorical analogies are made between the visual scene and the “auditory scene” in music, and between visual imagery and auditory imagery. Sound is time-dependent, but the understanding of a visual scene is tied to a sequence of eye movements. Vision happens in time, just as sound happens in time. Visual grouping and tracking allows for the recognition of images, while auditory grouping allows for the recognition of musical phrases.

Active Vision/Active Music

In pursuit of a music that requires one to get involved. The ambiguity of music not only points to connections within reality and furthers the interweaving and cross-relation of earlier, existing and later, delineating dialectic procedures which correspond to reality, but also clarifies the development of opposing models/opposing-thought-models . . . in order to (symbolically) urge their change [18].

My work on the whole has examined some of the ways the computer and cyberspace are said to mimic physical reality: what it means to live in a simulated environment, what is amplified, and what is lacking in the simulation [19]. In 1996, I began exploring the use of a custom-designed instrument for sound performance with eye movements. I first developed a system using simple video color tracking. There are numerous shareware applications that will take the input of a video capture card and analyze the position of certain colors in almost real time. If the eye is kept stable or a video camera is attached to the head, a slow but accurate data stream of the position of the dark pupil can be obtained. More advanced systems compensate for natural head movements and use a combination of tracking both the pupil and a reflected light on the cornea.

Gape, my first performance using eye tracking, used an eye-tracking device created as part of the diploma project of An Reich at the Academy of Media Arts Cologne under the supervision of Dr. Siegfried Zielinski and Phillip Heidkamp

[20]. Currently I am using a video tracking software called BigEye which is available through STEIM [21]. In this new system, I use BigEye to send MIDI information to Opcode’s Max [22]. I then create a Max patch that uses the information to trigger and manipulate sound samples with the Max plug-in AiffPlayer 1.5 created by Shuichi Chino.

The first system I developed allowed the performer to access a grid of nine words spoken by a single human voice. With *Gape*, the audience perceives a performer trying to “speak” a coherent sentence (see Fig. 1). Physically paralyzed by the need to be accurately received through a video signal routed to the computer, I moved my eye to each of the nine directions in sequence which in turn triggered a sound sample of my voice. However, since the system was sensitive to even the slightest eye movement, and these movements were not completely under my conscious control, I was unable to keep from responding to distractions. Instead of speaking a coherent sentence, I created a collage of spoken text with multiple meanings. This work was performed as a part of *Meme Me: Identity and the Replication Age* at Artemisia Gallery, in Cache at Columbia College, Chicago, in conjunction with ISEA97, and as part of a performative lecture at Imagina98 [23].

I designed the interface using the grid format to relate metaphorical connections between the computer screen and the retinal image. The screen is made of a flat grid of pixels, and the retinal image is a flat projection of color and pattern. The retinal image itself lacks the depth and meaning of the real world; it is only through the process of interpretation that an understanding of the world is formed. In a similar way, information (in this case, the words of the sentence) stored on the computer has no real meaning until it is interpreted, not only by the computer program but also by a human interacting with the machine.

In *Gape*, the image of the eye—usually the receiver rather than the transmitter of an image—is received by the computer by way of its video capture card. The computer then takes this very material information (the bits and bytes that make up the image) in real time and translates it into sound,



Fig.2. Carol Genetti performing *Inside the Mask* at Artemisia Gallery, September 1998.

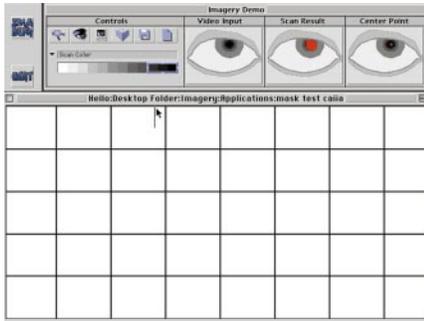


Fig.3. The imagery interface by An Reich in demo mode running the *Inside the Mask* application.

which is then perceived by the ears of the viewer. In a metaphorical sense this process endows the computer itself, along with the viewer/listener, with the capacity for synesthesia.

In the summer of 1998, I wanted to develop the interface for live sound further, so I began working with experimental vocalist Carol Genetti [24]. I had heard Genetti perform with Eric Leonardson, and I found her vocalizations to evoke images of multiple voices. We wanted to consider how a practicing musician might use a tracking instrument. I developed a custom instrument using her shadow as the control input instead of the eye and a variety of vocal tones which she could use to create harmonies while singing.

Genetti wanted to be able to "grab" her own voice from the air to create complex harmonies, so I sampled several sustained vocalizations. We worked together for several weeks and developed a system in which her shadow would be the trigger for a grid of eight sound samples. In addition to the sustained sounds from Genetti's own voice, I also recorded city sounds from the immediate environment. In this work the visual scene and the auditory



Fig.4. Performing with the eye tracking device, *Inside the Mask*, September 1998. The head must be stabilized for effective tracking; in this case a metal device is used.

scene become tied together in real time (Fig. 2). Genetti and I both felt that in this performance, the shadow represented another identity, a second self.

Also in 1998, I produced a recording of a large number of voices speaking text in various languages. The text chosen was determined collaboratively by participants in the Interstices Symposium (in conjunction with CAiiA 98), whose own voices were used in the recording. I used these samples to develop a more complex text-addressing system for the eye tracker based on the idea of amplitude "zones." Since it was difficult to precisely control eye movements in a complex grid of 30 or more sounds, I developed a patterning system for the tones based on their amplitude. In performance, I could saccadically sweep my eye into an area and precisely control timings of loud and soft tones. Once I was in a zone, I could fixate and finely adjust movement to access a precise piece of text (Figs. 3 and 4).

This work is related to the comprehension of spoken language, one area where the visual and aural senses work seamlessly in conjunction. If what one hears and what one sees do not correspond, the

effect is jarring to the perceiver (for example when watching a dubbed film or communicating through a teleconferencing system). There are many other examples of common sensory crossovers: the aural and tactile senses work together in playing a musical instrument (such as when a violinist measures the pressure of her fingers against the instrument's strings), while the visual and tactile senses work in tandem when using a keyboard or mouse.

The spoken-text piece, along with the custom shadow-tracking piece created for Genetti, was called *Inside the Mask* in reference to Carl Jung's ideas about the mask and the shadow self [25]. The work was performed in Chicago as part of the MiXing Sound Art Festival. Invented instrument musicians Steve Barsotti and Eric Leonardson improvised with us for two performances [26].

In early 1999, inspired by the work I had done with Genetti, participation in the Varenus Workshop on Cognitive Models of Dynamic Geographic Phenomena [27], and by a workshop with soundscape composer Andra McCartney, I began to explore connecting visual and auditory scenes in my work.



Fig. 5. Audience member Jeff Lancaster plays the shadow map instrument during the performance evening “The Final Mix.”

Project Varenus aims to foster research in three strategic areas of geographic information science: cognitive models of geographic space, computational implementations of geographic concepts, and geographies of the information society. The workshop on Models of Dynamic Geographic Phenomena, held in Pittsburgh, Pennsylvania, in October 1998 and led by Stephen Hirtle and Alan MacEachren, consisted of a multidisciplinary panel of participants. One topic that interested me was the mental model of time, particularly in relationship to space and time. I was interested in how dynamic geographic phenomena related to sonic interaction and the auditory scene. Since there are few models for the representation of dynamic geographic phenomena, we looked at other symbolic systems for the representation of time, such as the Laban system of dance notation, musical notation, and the notation of juggling patterns.

In the workshop with McCartney, which was held in December 1998, I along with several other artists went on a sound walk to record in the area of West Town in Chicago. I used the sampled sounds as source material for creating an instrument using shadows and a projected map of the area. I designed this instrument to be played with a mallet-like stick. As the performer moved the end of the mallet into an area of the projected map, he or she was able to access the sounds recorded from that area of the city. In practice, playing this instrument was much like playing a gong. Once a sound was accessed (for example the sound of a car moving across a metal bridge), the performer would move the shadow away and the sound would

slowly amplify. This instrument was used in the improvisational performance evening “The Final Mix” with Pauline Oliveros, Carol Genetti, Olivia Block, Fred Lonberg Holm, and Robbie Hunsinger in February 1999 (Fig. 5).

Conclusion

Several insights came out of the performances of these works. First, and most important for me, I found that at several points during improvisational performance with the eye-tracking device, I felt I was able to control my eye in a very precise way to create specific sounds. In other words, the eye-tracking instrument in improvisation could produce the same feeling for the performer as improvisation with a traditional instrument, so that the process became automatic. David Rosenboom describes this effect in his monograph on nontraditional musical instrument interfaces: “In an ongoing improvisation situation, one may intuit the likelihood of occurrence of events, possibly involving unconscious calculations of event probabilities and, in rapid-fire sequences, predict event occurrences along with their precise timings, while attempting to execute events synchronous with these predicted timings. One senses that a synchrony is about to occur and makes a decision to ‘go for it’ more rapidly than one can utilize slower, reasoning processes” [28].

Another insight was related to significant similarities and differences between seeing and hearing. Is looking at something intensely the same kind of process as *listening* to something intensely? Unlike the eye, the ear does not have the ability to scan something several times. In the design of the interface for eye-tracking music, it seemed that the simpler the visual aspects of the interface, the more effective it was for playing music. A complex visual can distract from the performer’s ability to listen intensely while performing. Sometimes while playing the instrument, I felt completely unaware of seeing anything at all, but was purely focused on the sound. The visual image became nothing more than a blur of color and form, and the sense of hearing took precedence over the sense of sight.

In terms of similarities, a correlation

between grouping and tracking was apparent and will be a further area of study with the instrument. The zone interface, organizing groups of amplitudes spatially, was a useful development in the design of the instrument. Do both the ear and the eye organize perceptual input into groups in similar ways? Certainly the perception of visual groups is well known and has been useful in the design of machine vision [29], but how are those mechanisms related to sound? Future work will be to explore the relationship between spatial and aural cognition by experimenting more with visual maps and the auditory scene and in the recognition of spoken language.

References and Notes

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2. For more detail on saccades, see B. Fischer and H. Weber, “Express Saccades and Visual Attention,” *Behavioral and Brain Sciences* 16, No. 3, 553-610 (1993); Fischer and E. Ramsperger, “Human Express Saccades: Extremely Short Reaction Times of Goal Directed Eye Movements,” *Experimental Brain Research* 57 (1984) pp. 191-195; Fischer and Ramsperger, “Human Express Saccades: Effects of Randomization and Daily Practice,” *Experimental Brain Research* 64, (1986) pp. 569-578; Fischer and L. Rogal, “Eye-Hand-Coordination in Man: A Reaction Time Study” *Biological Cybernetics* 55 (1986) p. 253; Fischer and Weber, “Saccadic Reaction Times of Dyslexic and Age-Matched Normal Subjects,” *Perception* 19 (1990) pp. 805-818; Fischer and Weber, “Characteristics of ‘Anti’ Saccades in Man” *Experimental Brain Research* 89 (1992) pp. 415-424.
3. Irvin Rock, *Indirect Perception* (Cambridge, MA: MIT Press, 1997) p. 223.
4. See Fischer’s work [2].
5. A.L. Yarbus, *Eye Movements and Vision* (New York: Plenum Press, 1967).
6. “The close link between attention and eye movements is supported by neurophysiology. Cortical centers containing neurons that are active before eye movements also contain neurons (sometimes the same ones) that are active before shifts of attention while the eye is stationary. . . . Some investigators have gone as far as to suggest that shifting attention to an eccentric location while the eye remains stationary is equivalent to planning a saccadic eye movement.” From *The MIT Encyclopedia of Cognitive Sciences*, mitpress.mit.edu /MITECS.
7. Percy Bysshe Shelley, *Prometheus Unbound*, Act 3, Scene 4.
8. Simon Baron-Cohen, *Mindblindness: An Essay on Autism and Theory of Mind* (Cambridge, MA: MIT Press, 1995) p. 117.
9. James Elkins, *The Object Stares Back: On the Nature of Seeing* (New York: Simon & Schuster,

1996) p. 27.

10. Baron-Cohen [8] p. 97.

11. Baron-Cohen [8] p. 98.

12. Elkins [9] p. 21.

13. Christopher W. Tyler, *An Eye-Placement Principle in 500 Years of Portraits* (San Francisco: Smith-Kettlewell Eye Research Institute, 1996).

14. Luciano da Fontoura Costa, *Minding Vision* (São Paulo, Brazil: Cybernetic Vision Research Group IFSC-USP, 1996). See also da Fontoura Costa, "Dialoguing on Julesz's Latest Masterpiece: A Personal Review of Dialogues on Perception," *Real-Time Imaging* 1 (1995) pp. 159–162, and "Topographical Maps of Orientation Specificity" *Biological Cybernetics* 71 (1994) pp. 537–346 .

15. See Joachim-Ernst Berendt, *The Third Ear: On Listening to the World* (New York: Henry Holt, 1985) for a detailed discussion of the cultural dominance of the eye and a discussion of "inner seeing."

16. Berendt [15] p. 12.

17. Brian D. Josephson and Tethys Carpenter, "Music and Mind: A Theory of Aesthetic Dynamics," www.roma1.infn.it/rog/group/frasca/b/bj5.html.

18. Gerhard Stabler, "Not Dream, Dream: Reflections on Composing," lecture, Darmstadt, 1994.

19. For a retrospective of work from 1993–1997, see Andrea Polli, "Virtual Space and the Construction of Memory," *Leonardo* 31, No. 2 (1998) pp. 103–09.

20. See www.khm.uni-koeln.de/~an/imagery/.

21. See www.xs4all.nl/~steim/software.html.

22. See www.opcode.com/.

23. For a shockwave simulation of *Gape* see homepage.interaccess.com/~apolli/gape.htm.

24. Carol Genetti is a vocal sound artist living in Chicago. She employs Western opera, Bulgarian folk singing, and extended vocal techniques to create a world of sound that is mysteriously "insistent and relentless . . . evocative," as Carmela Rago of the *Chicago Reader* has stated. Carol's most recent work with Chicago-based instrument inventor Eric Leonardson, with whom she toured throughout Germany, can be heard on their CD *Animus*.

25. Carl Jung, *Collected Works*, Vol. 9, Part 2, 2nd ed. (Princeton: Princeton University Press, 1968) pp. 8–10.

26. Steven A. Barsotti is a sound artist living and working in Chicago. His work includes studio/tape-based formal explorations of sound, works for radio broadcast, site-specific sound installation, electrical/acoustical instrument building, and sound as an integral part of performance. He has had his work played on radio in Chicago and Berlin as well as participation in radio festivals in Canada and Ireland. Eric Leonardson is an electroacoustic composer, performer and improviser, instrument inventor, radio artist, and sound designer. His works for dance, theater, radio, film and video have been heard in broadcasts and performances throughout North America, Europe, and South Africa. For more information about Leonardson's work and "sound thinking" see www.tezcat.com/~eleon/.

27. *Cognitive Models of Dynamic Geographic Phenomena and Their Representations, A Varenius Workshop*. www2.sis.pitt.edu/~cogmap/ngcia/

28. "In music, this relates directly to performing

actions that can manifest in a special state of alertness, with great speed, and in close communication with other performers. . . . Finally, a state of performance consciousness is sometimes achieved, especially during improvisation, in which one can be surprised by one's own actions and choices, seemingly arising from a special part of the mind, separate from that normally associated with conscious determinations." David Rosenboom, *Extended Musical Interface with the Human Nervous System: Assessment and Prospectus*, Leonardo On-Line Monograph, mitpress.mit.edu/e-journals/Leonardo/.

29. *The MIT Encyclopedia of Cognitive Sciences* [6].

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- The WWW Virtual Library's Oculomotor Page*. info.ox.ac.uk:80/~eye/. This page is to contain a general introduction to the field, as well as information about ergonomics, ophthalmology, physiology, and psychology and the neurosciences.

Andrea Polli is a digital media installation and performance artist living in Chicago, Illinois. She has exhibited and lectured nationally and internationally. Most recently she performed at the Imagina '98 Conference and at The Digital Whole in Monaco and presented her work at the CAiIA '98 conference, "Re-Framing Consciousness." Recordings of *Inside the Mask* are available on The Mix compilation produced by Artemisia Gallery and the 1999 Harvestworks residencies compilation.