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Haptic Control of Eye Movements

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Table of Contents

Figures & Tables

Abstract

Eye-hand coordination is crucial to many important tasks. A NLDS framework assumes that eyes and hands are interacting facets of one complex oculo-motor system in which physiological and task constraints interact to shape overall system behavior. Participants (N=13) in this study played a first-person video game with either a traditional GameCube controller or a motion-sensing Wiimote controller. Eye movement and hand movement time series data were analyzed with nonlinear statistical methods in the search for evidence of multifractal structure. Multiple Hölder exponents were obtained for both conditions, indicating that eye and hand movements were multifractal. Hand movement data in both conditions contained brown noise indicative of short-term correlations in the time series. Eye movements in both conditions contained pink noise indicative of long-term correlations although the signal in the Wiimote condition was pinker, suggesting perhaps more orderly eye movements. Mean eye movement Hölder exponents in the Wiimote condition were pinker than in the GameCube condition. Eye movements change depending on the constraints of the hand.

Keywords: visual perception, dynamical systems, hand movements

Haptic Control of Eye Movements

People use their senses to navigate and gain information from their environments. Many activities require a skilled coordination of multiple senses. For example, when people are looking for their keys on the shelf, they do not simply stare at the surface of the shelf. People will move their body to gain different vantage points of the shelf and use their hands to run over or near the surface of the shelf to aid in finding their keys. However, current sensory research indicates as though each sense operates independently. An integrated understanding of human sensory functions could enhance our ability to design and operate machinery.

Vision

Most visual search research has focused on the visual system as a separate process from other sensory modalities. However, this research has not been fruitless. For example, people look at the location of an object where relevant information was located, even though that spot no longer holds useful information (Richardson & Spivey, 2000). People look at the location of information even if they remember the stimulus that occupied that space. People identify target objects more quickly if they see a preview of the scene (Castelhano & Henderson, 2002). *Change blindness* is the inability to discern when a small object in a scene changes. People are more likely to notice items in a task depending on object orientation and coloration. For example, people are more likely to notice a red ball disappearing in a forest rather than a leaf (Delvenne & Bruyer, 2006).

Visual attention is almost inseparable from visual search literature. Attention usually shifts toward objects that are novel, those that are different from other stimuli. Stimuli that are faster, brighter, or larger tend to attract attention (Desimone & Duncan, 1995). Attention in the visual system is biased toward objects that have not recently been attended (Klein, 2000). This tendency to avoid recently fixated object is called *inhibition of return*. Traditional measures of visual perception are response times (e.g. Wolfe, 2007) and eye movements (e.g. Zelinsky, 2008). Studying eye movements has been a traditional way to study attention and has become more precise with the invention of eye-tracking cameras.

The perceiver's history shapes the behavior of eye movements. For example, people are able to predict a system that follows simple patterns more accurately than a complex or random pattern. People using coded lights to complete actions with a robotic arm were able to react more quickly when the lights followed a predictable sequence (Adams & Xhignesse, 1960). Eye movements change depending on the intention to interact with an object. For example, people's *fixation* patterns, small stops in the eye movements, change depending on whether they want to grab an object or look at the object (Bekkering & Neggers, 2002). This indicates that visual search may not be independent of the haptic system.

Haptic

Pointing is hypothesized to be the building block of other motor processes (Bootsma, Fernandez, & Mottet, 2004). People can form stable patterns of pointing when switching between targets. The pattern is destabilized when the pointing task changes or when the task transitions to a more difficult task. Fitt's Law is a formula for predicting hand movements; the patterns of motion become more complex than expected from increasing the number of targets and difficulty. Fitt's Law suggests that perhaps hand movements are not a linear system. Though eye movements may be measured without haptic input, hand movements are rarely utilized without visual input. It is likely that the two systems become a functional unit when performing many kinds of tasks.

Vision and motor

Recent research indicates that eye movements and hand movements may interact in search tasks, such as searching for a target. However, little is known about the interaction of the visual and haptic senses. Some theories separate the visual and haptic systems into two separate entities (Thelen & Smith, 1994). For example, the *Common Command* hypothesis is that the signal for movement originates from a central executive in the brain, which branches out to the different modules of the perceptual system (Binstead et al., 2001). However, it seems more likely that the visual system is goal oriented, with many possible forms of input, such as hand movements.

Eye-movements may be related to hand-movements but the exact nature of this link is unknown. Currently perceptual psychologists are divided into two major camps; those who believe that perception is direct, and those who believe that perception is indirect (DeLucia, 2008). *Indirect perception* describes the idea that all perceptions have mental representations. *Direct perception* describes the idea that sensory organs are capable of extracting information from the environment without mental representation as an intermediate. If perception is indirect, the *common command* hypothesis is feasible. The central executive is sending out a common encoded message to the hand and eye, which is decoded separately by each organ or a module in the brain for that respective organ. If perception is indirect, the eye and hand should be able to react skillfully to a situation, without a central command center coordinating their movements.

The *linked control* is a hypothesis for why eye-movements tend to gravitate toward a target when the hand is nearing the target (Binstead, Chua, Helsen, & Elliot, 2001). The linked control hypothesis is that hand and eye movements are prepared and executed together but are thought to be contained in parallel systems (Vidoni, McCartley, Edwards, & Boyd, 2009). However, the eye always reaches the target before the hand- just as the hand reaches maximum acceleration, which cannot be explained by linked control (Vidoni, McCartley, Edwards, & Boyd, 2009). If this hypothesis is correct, eye and hand movements will be similar in amplitude but not end location. Computational models have approximated human performance using the linked control hypothesis (Blohm & Crawford, 2007). The eye can make more movements, called saccades, when it is the only perceptual system engaged in a search; however, it typically takes people longer to identify the target without use of their hands (Liesker, Brenner, & Smeets, 2009). Many tasks require the cooperation of eye and hand movements.

Table hockey, like many other sports, requires the coordinated effort of eye and hand movements. However, what happens when some sensory modalities are removed from the game? People playing virtual table hockey increase the accuracy of their movements the more sensory modalities are added to the system (Nam, Shu, & Chung, 2008). People report that boxes are heavier when they watch someone else lift the boxes (Schuzt-Bosbach & Prinz, 2007). They react to the box as if it is heavier if they are told to lift the box after they have seen someone else lift it. An accurate perception is not necessary for increased performance. People are able to grab hidden objects with more accuracy if they can see the object’s reflection in a mirror (Craighero, Bello, Fadiga, & Rizzolatti, 2002). The mirror image should distort people’s hand movements but the added sensory input helped guide movements even though it was not accurate information.

Pointing at an object activates the intention to interact with that object (Davoli & Abroms, 2009). As a result, more fixations, clusters of gaze points, should appear on objects that the participant intends to point at. People make increased numbers of fixations near the hands, so pointing at an object should increase fixations around it (Davoli & Abroms, 2009). People are more likely to remember objects that their hands were near, even in a computer display (Cosman

& Viscera, 2010). Furthermore, presence of a hand near an ambiguous optical array can influence which parts are perceived as the figure and ground.

Haptic information influences perceptual illusions. The *Müller-Lyer illusion* is when open or closed arrows on the line segments influence a line segments' perceived length. People who viewed Müller-Lyer illusions had different eye-movement amplitudes and endpoints, dependant on closure for the line type (Binstead, & Elliot, 1999). The Necker cube is an illusion where a three-dimensional box will shift orientations, called a *perceptual flip*. People who are holding Necker cube models perceive fewer perceptual flips than those who watch someone else hold the cube (Bruno, Jacomuzzi, Bertamini, & Meyer, 2007). Perception is influenced by goals. People either looked at a Müller-Lyer illusion or had a task, estimating line length, while eye movements were measured. Eye movements for perception are statistically different from those used to direct action (Bruno & Franz, 2009). This indicates that the visual and motor systems are not completely autonomous entities.

People work more efficiently in real-world environments than in virtual environments (Arnold, Farrell, Pettifer, & West, 2002). People in a virtual reality environment were to bend a wire around an obstacle, with either no background or a background that would help them orient around the target. The background provided extra contextual clues about the location of the target that allowed for movements that are more accurate. It is possible that the lack of tactile feedback in the virtual environment was responsible for the increased response times and error rates. However, there are virtual environments where people can become highly skilled without haptic feedback.

Video games and perception

Video game playing has been linked to improved eye-hand coordination (Griffith, Voloschin, Gibb, & Bailey, 1984). Experts at games have highly organized knowledge structures that generalize too many types of games (Day, Arthur, & Gettman, 2001). Experts are also able to pay attention to relevant parts of the screen better than novice players (Tomlinson, Howe, & Love, 2009). For example, most games that share a genre have similar movement mechanics that will be familiar to an expert, even if they have not played that particular title.

Eye movements can be used as a measure of the cognitive load of a participant while they play video games (Lin, Imamiya, & Mao, 2008). This cognitive load is affected by what kind of input device the player is using to interact with the game. Mouse movements do not seem to change across difficulty or cognitive load (Lin, Imamiya, & Mao, 2008). Input devices, such as joysticks, that integrate multiple senses produce reports of greater levels of comfort and ease of performance (San Agustin, Mateo, Hansen, & Villanueva, 2009). This indicates that participants felt that such systems were more natural and perhaps a better reflection of how they interact with real-world objects. Learning to control an artificial system has implications outside of video games.

Humans and machines interact within environments. *Anthropometry* is the design of hand tools, workspace, and vehicle passenger/driver compartments (Guastello, 2006). Those who used a mouse have more skeletal and muscle deformations in the hand than those who use a keyboard (Gustafsson & Hagberg, 2002). For, example, participants used a traditional mouse and a new mouse designed to ease stress on the hand to complete a normal workday. Participants reported that the old mouse was more comfortable but EMG detected fewer hand movements in the prototype mouse condition. However, participants using the old mouse made fewer typing errors. Even though the prototype mouse was more naturalistic, the performance in the old mouse condition was more efficient. The user history of the mouse-users created a situation in which a more naturalistic control condition was less intuitive to use.

Small cameras are attached to some surgical instruments (image-guided interventions) to facilitate an operation without exposing the organs to open air. This type of surgery is less risky to the patient and leads to faster recovery times. However, this method of surgery is not perfect. Surgeons using this method of surgery suffer from *degraded depth perception*, difficulty in translating a 2D image to 3D motions (DeLucia, Mather, Griswald, & Mitra, 2006). This is also a problem in video games; the screen is a 2D object that the player must perceive as a 3D surface. Surgeons also are affected by *reduced field of vision* (RFOV); the surgeon can only see a small portion of the inside of the organ, which could disorient the operator (DeLucia, Mather, Griswald, & Mitra, 2006). People who previewed an object navigated with a remote camera more quickly. Video games are often set in a first person perspective, which does not allow the player to see threats coming from the sides or behind the character. Many modern video games have added a map feature so players to do not get lost in the area. The cameras used in surgery also cause *degraded motion detection*, the inability to determine how quickly the device is moving (DeLucia, Mather, Griswald, & Mitra, 2006). The surgeon is often a *passive viewer*; the surgeon cannot control the camera and the surgical instrument at the same time (DeLucia, Mather, Griswald, & Mitra, 2006). Passively viewing objects may cause an increase incorrect turns. In video games, the participant is not actually navigating the environment and does not have all the sensory feedback from the real world, which may result in the participant becoming lost. The control of these surgical instruments is similar to that of video games. Furthermore, surgeons have been trained to perform surgeries with their own eyes and hands. People performing surgery-like tasks take longer and make more mistakes when the surgery method is different from the way in which that were trained (Holden, Flach, & Donchin, 1999).

Dynamical systems

Historically, cognitive concepts have been conceptualized as permanent fixtures across situations that exist separately from moment-to-moment representations of environmental stimuli (Smith, 2005). Intentions are neural representations in the brain's modular components. The interaction of components is what causes differences in response times. Unfortunately, there is no way to test the assumption that there are modules interacting (Van Orden & Holden, 2002). A modular hypothesis, such as the c*ommon command*, would predict that changes in the hand's task should not affect eye movements.

"Statistical analyses buy into intellectual assumptions" (Carello & Moreno, 2005). Traditional statistical measures assume a standard normal curve. However, data from biological systems may not be orderly enough for the rules of statistical analysis. Biological systems are complex, iterative, and self-organizing (Van Orden & Holden, 2002). For example, an ANOVA requires that error terms are independent of one another - which is an assumption that one cannot make in data coming from the same participant (Gilden, 2001). An alternate way to analyze data is through nonlinear dynamical systems methods. One characteristic of nonlinear dynamical systems is that data form a *fractal* pattern. As a non-fractal object is enlarged, the details of the object are lost (Liebovitch & Shehadeh, 2005). Fractals are self-similar (resemble self at different magnifications), scale-dependant (the measure is dependent on the ruler you use), and the average size depends on the scale (Paulson, 2005). In traditional statistics, more data move the mean closer to the hypothesized population mean. In nonlinear dynamical systems, there is no hypothesized population mean; more data change the distribution of the data (Liebovitch & Shehadeh, 2005).

According to the non-linear dynamical systems (NDLS) approach to visual memory, eye movements should show self-similarity, similar structure across magnification, which is a hallmark of dynamical systems (Paulson, 2005). Dynamical systems are *apparently random*, because most people try to understand them in terms of linear causality. The apparent randomness of some variables is actually due to previous iterations of the system (Aks, 2005). Dynamic systems theory can help explain why some researchers do not find evidence of memory in visual search; they use traditional means of analysis, which means they attribute important factors to error. Response times follow a fractal pattern, but in most studies, the trails are analyzed in a random order. This ordering destroys the natural pattern of data (Gilden, 2001; Holden, 2002). This has led some (e.g., Zelinsky, 2008) to the hypothesis that the oculomotor system is a dynamical system. That is, moment-to-moment differences in eye movements are the product of earlier eye movements.

Another hallmark of a dynamical system is that many factors influence outcome. People may have a predisposition to manipulate objects in their hands. People react to targets that are projected onto the palm of their hand more quickly to those which are projected onto the back of their hand (Brown, Morrissey, & Goodale, 2009). People are naturally inclined to manipulate objects which are in the palms those on their hands, but not of the backs of their hands.

Fourier analysis checks for correlations within a time-series (Aks, 2005). Jagged data are often produced by complex dynamical systems. A Fourier analysis decomposes the waveforms into simple waves and then plots power/frequency to determine which simple wave best fits the data. A linear plot of the logs of power and frequency will give us a line, the slope of which is the power law. A slope near one indicates pink noise (1/*f*). The magnitude of the logs will show how strong the correlation is between the data points in the time-series. The Hurst exponent is a measure of the fractal dimension of an object (Aks, 2005). Nonlinear measures of behavior, such as the Hurst exponent, are a more appropriate measure for living systems (Holden, 2002).

Wavelet Transform Maximis-Modula (WTMM) is an analysis technique that takes the local Hurst exponents (called the Hölder exponent) and compares them over different time scales. If different fractal patterns are found across different scaling lags, then the distribution is a multifractal (Muzy, Bacry, Arneodo, 1993). Multifractals are data distributions with two or more fractal patterns embedded in the data.

The motor system extends beyond an organism's body; tools can also become a functional part of the motor system. A *ready-to-hand* is a state in which a person is acting skillfully with a piece of equipment (Dotov, Nie, & Chemero, 2010). This is characterized by perceiving the tool as integrated with the task it is used for, little thought is given to the form or use of the tool itself. An *unready-to-hand* state is when a tool is not intuitive to use. People think about the tools and pay careful attention to the task. *Present-to-hand* state occurs when the tool is no longer perceived as tool, but rather an extension of the hand. People played a computer game in which the mouse pointer acted as repeller for virtual sheep; the objective was to keep the sheep together. People's hand motions reflected 1/*f* noise similar to pink noise when they were in the ready-to-hand or present-to-hand state. People's hand motions reflected 1/*f* noise similar to white noise when they were in the unready-to-hand state. A more naturalistic hand motion was correlated with pink noise patterns (Dotov, Nie, & Chemero, 2010). Researchers concluded that people see a tool as part of themselves, at least until something perturbs the system.

Study Overview

This study explored the interaction between hand and eye movements, using dynamical systems as a framework. Recent advances in video gaming technology allowed us a unique opportunity to study the interaction between the visual and haptic systems. The Nintendo Wii allows users to interact with games in a more naturalistic way, using point-based controls instead of mapping movements onto buttons. This interface took players from the traditional controllers to a more naturalistic hand-movement control option. Traditional control schemes have mapped movements and actions onto a flat surface with buttons. Some of these games have been rereleased with the new motion controls for the Nintendo Wii. For example, *Metroid Prime* released in 2002, has been rereleased as part of the *Metroid Prime Trilogy* with the ability to aim the cannon using the Wii Remote.

If the visual and motor systems are separate, the type of controller used should not affect eye movements. However, we predict the type of input device used to interact with a game should affect the pattern of hand movements and eye movements. If the participant is familiar with one of the control types, they should experience the controller as a ready/present-to-hand tool. Specifically, eye movements in the motion control condition (Wii) will more closely resemble pink noise than the eye movements in the traditional control condition (Gamecube).

Method

Participants

Research participants were 13 undergraduate students enrolled in a General Psychology course at the University of Central Oklahoma. The mean age was 21.5, there were five males and eight females. Two participants identified themselves as having high exposure to video games, and two identified themselves as familiar with the Wii controller; four participants identified themselves as a gamer that was also familiar with the Wii controller. The two participants that identified themselves as gamers and the four that identified themselves as gamers and familiar with the Wii controller were removed from the second analysis, to control for the effects of participant history. All participants reported normal to corrected-to-normal vision. This research project fulfilled part of an assignment for the general psychology course offered at the University of Central Oklahoma. All APA ethical guidelines and rules were followed in this experiment.

Materials

Participants' eye movements were measured via corneal and pupillary reflection using an Applied Sciences Laboratory Eyetracker 5000 Series. This system samples eye movements at a rate of 60 Hz and uses near-infrared technology to track gaze position relative to a given scene location. The eye tracker monitors gaze directions while the participants search a display. The eye-tracker monitors the light reflected off the eye from a near-infrared source and interpolates gaze position. This allows the researchers to gather data on participant's eye movement patterns and pupil dilation.

Participants viewed a Dell Optiplex 755 computer with 4 GB of RAM and an Intel CORE 2 DUO processer and a 32'' Elo Touchsystems LCD touch-screen monitor (refresh rate = 60 Hz, resolution = 1024 × 768) from a distance of approximately 104 cm— subtending a vertical visual angle of 16.31° and a horizontal visual angle of 21.32°, left and right of center. The games were also displayed on the Elo Touchsystems monitor. The windowless laboratory was dark except for ambient light produced by the monitors and the eye-tracking system—no more than .10 lux. The researcher's computer was a Dell Optiplex GX620 computer with an

Intel Pentium 4 CPU and two GB of RAM. The researcher computer was in view of the participant, however the monitor was not visible to the participant.

Thumb movements were captured by a 12-megapixel Sony handheld camera. The video quality was reduced to 30 Hz for analysis. Participants wore a black Velcro strap with white Velcro squares spread every 90° on the meta carpal section of their primary hand's thumb. The analysis software MaxTraq v 2.19-015 used the contrast between the white and black Velcro to track the participant's thumb movements. MaxTraq generated a time series of X or Y coordinate locations for thumb movements for each participant.

Participants played both versions of *Metroid Prime* on a standard Nintendo Wii. They used the standard Wii remote to control the character in the Wii condition. They used a standard Gamecube controller to control the character in the Gamecube condition. The stimulus presentation was controlled by the Nintendo Wii software. The Wii was connected to a 32'' Elo Touchsystems LCD touch-screen.

Design

Table 1

MANCOVA for RT and error. Covariate is previous experience with games.

Control type (within)	
Gamecube controller (traditional)	Hurst eye fixations, Hurst hand movements
Wii controller (movement)	Hurst eye fixations, Hurst hand movements

Procedure

Participants watched a three-minute video showing how to play *Metroid Prime*. The experimenter then calibrated the participant's eye using a nine-point calibration system. The experimenter gave a brief description on how to control the character as the video played. The participant was informed that the object of the game was to explore and gain new abilities that would allow access to new areas of the game. The computer screen channel was changed to the Wii's input channel. The participants were given time to explore the first room and become accustomed to the controls, the researcher would repeat any directions on the controls if the participant asked. When the participant indicated that they were ready, the experimenter started a timer. Participants played *Metroid Prime* for 20 minutes using the traditional controller and 20 minutes using the Wii controller. The controller type order was counterbalanced between participants. Before each controller condition began, the participants did a short series of stretches to prevent fatigue. Participants were recalibrated after the stretching exercises, if necessary.

Participants were free to navigate the game environment at their own pace for the 20 minutes and received no help on game objectives beyond the beginning scripts. However, the researcher would repeat control instructions, if prompted to by the participant. Their eye movements, hand movement, and game progress were recorded during the 20 minute play period. Participants started on the first stage of the game after the tutorial stage. The tutorial stage was skipped because players had more abilities, some of which could take the participant out of the first person viewpoint. Participants navigated the environment with the motion or traditional controller and avoided or disabled enemies to reach upgrades. No participant obtained the first upgrade.

Data Analysis

A repeated-measures MANCOVA was used on the Hurst exponents from the participants' data. The independent variable was controller type: Wii (motion) or Gamecube (traditional). Controller type is a within participants variable. The dependent variables were eye movements and hand-movements. The eye-tracker camera measured the reflection of the pupil to interpolate X, Y coordinates for gaze location. MaxTraq analyzed a video of hand movements to obtain X, Y coordinates for thumb movements. Co-variables were gaming skill and previous exposure to the traditional and motion controls. An Iterative Function Systems (IFS) Clumpiness test was used to verify the color noise of the data.

Gaze and thumb-movement data were trimmed to any data point within three standard deviations of the mean. Data were analyzed in R Statistics to obtain the Hurst exponent from eye movements and the hand movements in the motion and traditional controller condition.

The WTMM set graphs the strength of the attractor over different scales. If the data has a single attractor at one strength, it is a monofractal (Figure 1). If the data has multiple attractors at multiple strengths across scales it is a multifractal (Figure 2).

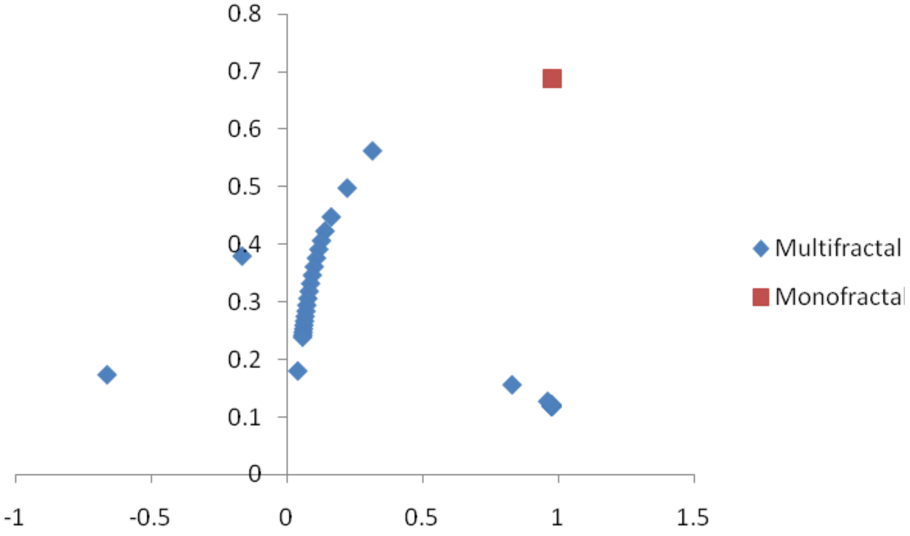

Figure 1. Hypothisized monofractal Cantor set and multifractal WTMM distribution.

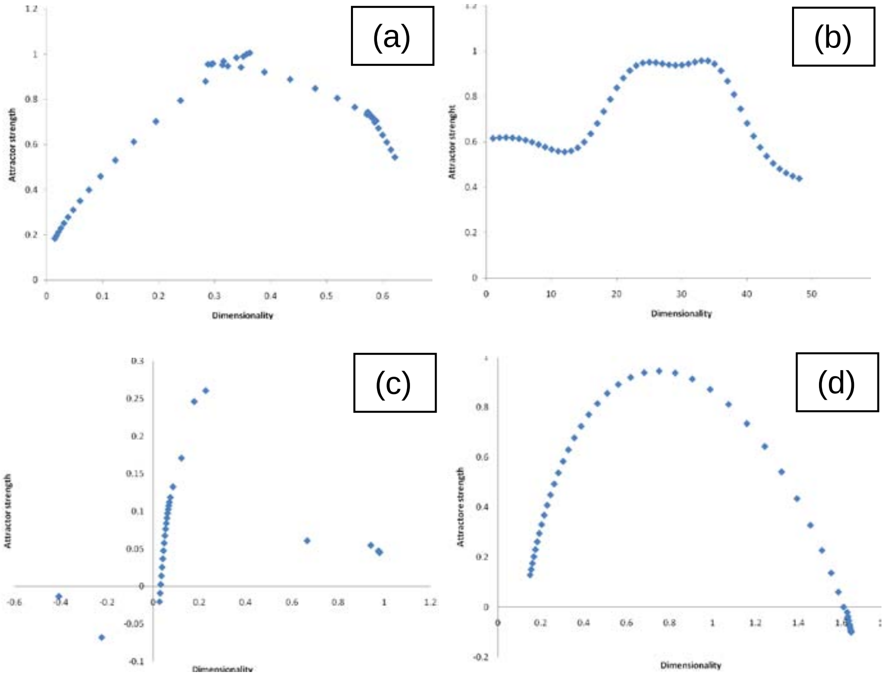

Figure 2. Cantor set for participant for: (a) eye-movement data using a traditional controller (b) eye-movement data using a motion controller (c) hand-movement data using a traditional controller (d) hand-movement data using a motion controller. The Cantor set indicates multifractality.

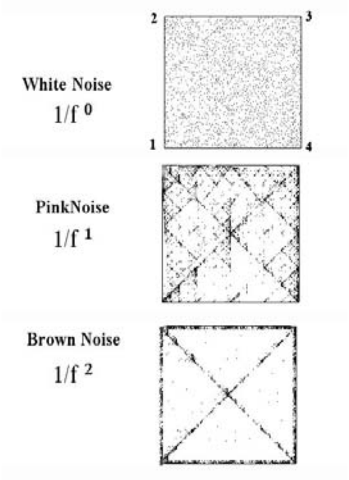

Figure 3. Idealized graphs of colored noise from Aks (2002).

The Iterative Function Systems Clumpiness test (IFS) is a way to graphically determine the color of noise of a data set (Aks, 2005). There are inconsistencies in how Hurst data are interpreted. The IFS test helped verify our interpretation of the data. White noise is a random distribution of data, there was no effect of history on the dependant variable. Brown noise is a heavy distribution of diagonal lines. Brown noise indicates that there are short-term correlations in the data. Pink noise is a series of nested triangles that resemble the Sierpinski Triangle. Pink noise indicates long-term correlations in the data.

Results

Nonlinear Dynamical Systems

The IFS clumpiness test revealed that thumb movements in both the traditional and motion controller were similar to brown noise ($1/f^2$). However, eye movements resembled pink noise ($1/f$).

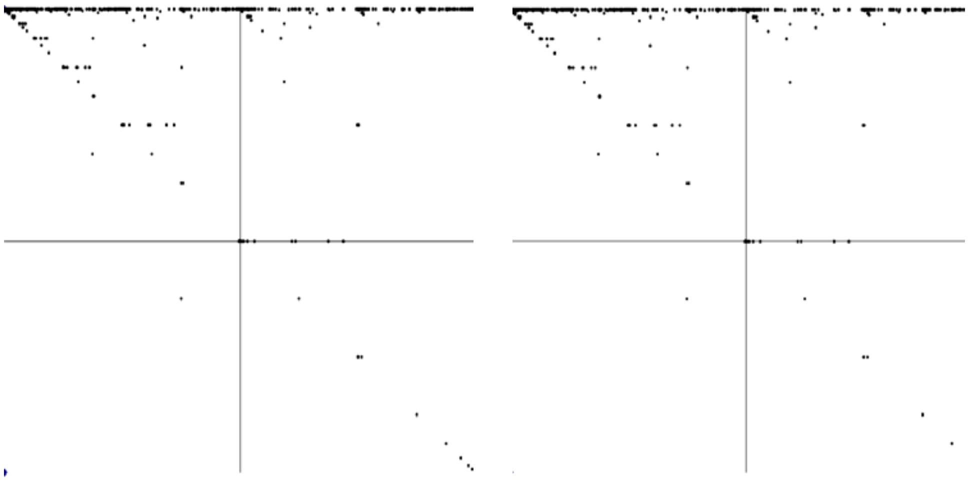

Figure 4. IFS clumpiness test results for hand movements in the traditional controller condition clump around the diagonals. This clumping pattern indicates brown noise.

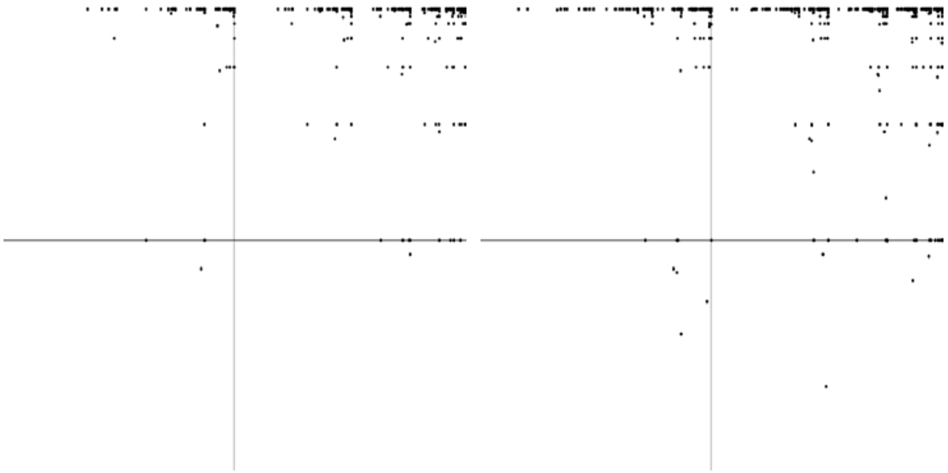

Figure 5. IFS clumpiness test results for eye movements in the traditional and motion controller conditions clumps into nested triangles. This clumping pattern indicates pink noise.

Traditional Analysis

A repeated-measures MANCOVA was conducted on the Hurst exponents of the eye movements and hand movements (Wilks λ = .002, $F(4, 6) = 909.6$, $p = .001$, $\beta = 1.00$, $\eta^2 = .998$). *Post hoc* test indicated that the participants that described themselves as gamers were significantly different in hand and eye movements than the non-gamers (Wilks λ = .221, $F(3, 8) = 7.313$, $p = .011$, $\beta = .87$, $\eta^2 = .733$). Hand movements in the traditional controller condition differed from those in the motion controller condition (t (12) = -3.237, $p = .007$).

A repeated-measures MANCOVA was conducted on the Hurst exponents of the eye and hand movements of participants (n =7) who did not identify themselves as gamers (Wilks λ = .055, $F(3, 3) = 17.34$, $p = .021$, $\beta = .86$, $\eta^2 = .945$). Eye movements in the traditional controller condition differed from eye movements in the motion controller condition (t (6) = -3.221, p = .018). Hand movements in the traditional controller condition were closer to white noise than those in the motion controller condition (t (6) = -3.343, $p = .016$).

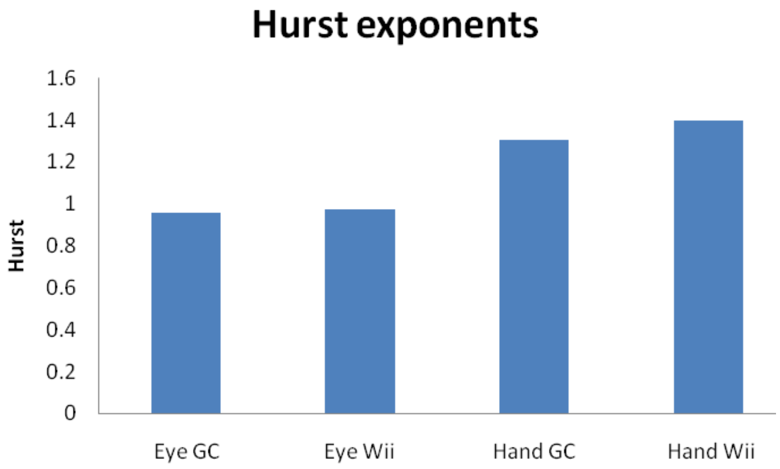

Figure 6. Hurst differences in traditional and motion controls by hand movements and eye movements.

Discussion

Results indicate that Hurst exponents are significantly different between the traditional and motion control conditions for thumb movements. Furthermore, eye and hand movements had significantly different attractor strengths. The research from this study did indicate a small difference in Hurst exponents between the traditional and motion controller conditions. However, the Hurst exponent for some participants was closer to pink noise in the traditional controller condition. This usually indicated that the participants were familiar enough with the traditional controllers have started to use the controller as a naturalistic motion. People who use traditional controllers, but not motion controllers, will have eye movements closer to fractal pink noise in the traditional controller condition. People find it easier to control a computer pointer with a mouse than controlling the pointer with an EEG system (Jones, Middendorf, McMillan, Calhoun, & Warm, 2003). A more natural system is not always going to feel more natural to the participant. The history of the organism plays a part in how complex behaviors can be executed.

Currently the investigation of visual search and hand movements is a new field. Dynamical systems theory is a more accurate way to describe noisy and seemingly unpredictable systems. Findings of fractal noise in eye and thumb movements provide compelling and converging evidence for the adoption of dynamical systems theory to describe perceptual processes. The findings of this study indicate that the *Common Command* hypothesis is incorrect. If the command to move the thumb or eye is originating in a central point in the brain, and moving on to other modules that encode the movement commands for their specific muscles, changing the movement constraints of the hand should not affect the eye.

The presence of colored noise suggests that eye and hand movements are dynamical systems. The eye movements in both controller conditions resembled pink noise. However, the traditional controller was closer to white noise than the motion controller, which suggests that motion controllers produce movements that are more naturalistic. These movements were significantly different from one another, suggesting that the motion controller was a more naturalistic control method.

The environmental constraints of video games provide a more naturalistic environment for the participant. It could be argued that the controller types are not equal in difficulty, and this imbalance in the conditions caused the lack of change in hand movements. However, hand movements do not change by manipulation difficulty (Lin, Imamiya, & Mao, 2008). One disadvantage to using video games as a stimulus was that the participants had different expertise levels. Experts in video game should be more able to pay attention to significant portions of the screen (Tomlinson, Howe, & Love, 2009). This meant that video game experts needed to be analyzed separately from the video game novices.

People playing video games may have suffered many of the problems shared with surgeons performing remote surgery. For example, the game was displayed on a 2-D screen, which could degrade depth perception and reduce field of vision. Navigating inside a virtual environment also lacks many of the other sensory cues. These cues could provide vital information for navigation. A video game may be more naturalistic than many traditional visual search tasks. However, the task is not entirely naturalistic.

The motion controller condition of this study required that the participants point toward a target with their arm to interact with that target. Modular hypothesizes, such as the common command and linked control, would predict that changing a controller would change a participant’s hand movements but not eye movements. However, the participant in this study had significantly different Hurst eye movements between conditions. However, the Hurst exponent does not tell which controller condition is more efficient. Changes in eye movement patterns suggest that more fixations are made around the hand when pointing at a target object (Davoli & Abroms, 2009). These changes could indicate that people are more likely to react quickly to something near their pointing hand, but react more slowly to objects distal of that hand.

A potential weakness of this study is that recording a game session made it impossible to separate discrete trials out of the session. Traditional items of interest, e.g. response time and error rate, could not be tested in this study. Furthermore, the participant’s history affected the outcome of the Hurst exponent. People who have learned to use a system with one type of controller may have interference when using a different type of controller (Jones, DeLucia, Hall, & Johnson, 2009). Eye and hand movement patterns may have changed over the course of the task due to changes in the goal of the participant. While playing the game, participants switched between exploring the environment and defending against attacks from hostile creatures. The eye movements in these two tasks may be different.

The results of this study add to our knowledge about the link between the visual and haptic systems. The results also have implications for fields such as video game design and human-computer interactions. Traditional hypotheses cannot account for the nonlinear data generated by a biological system. The movement constraints of the hand are affecting the movements of the eyes, which linear theories cannot explain. Nonlinear dynamical systems methodology is needed to accurately describe the data. A proper understanding of visual search is vital to the improvement of diverse activities such as remote surgery, tumor detection, virtual reality control, and driving.

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