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A Study of Human Balance and Coordination Using a Head Mounted Display

Daniel Gracia de Luna
The University of Texas Rio Grande Valley

A STUDY OF HUMAN BALANCE AND COORDINATION USING A HEAD MOUNTED DISPLAY

A Thesis

by

DANIEL GRACIA DE LUNA

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DANIEL GRACIA DE LUNA

COMMITTEE MEMBERS

Dr. Alley Butler

Chair of Committee

Dr. Emmet Tomai

Committee Member

Dr. Douglas Timmer

Committee Member

Dr. Dumitru Caruntu

Committee Member

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ABSTRACT

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Virtual Reality (VR) is growing with new technologies and applications. The new technologies help the user to feel more immersed in virtual environments, but interaction and immersion is an area that has not been well studied. Immersion is the feeling and reaction of users while they are in a virtual environment. This investigation is focused on the study of the human balance and coordination when human subjects are inside a virtual environment. Over 60 subjects are studied under an experiment, where their trajectory is captured and analyzed to identify possible differences or similitudes between male and female subjects.

DEDICATION

I dedicate this thesis to my parents, Daniel Gracia Gomez and Rosa Maria De Luna Cardenas, who had always support me and inspired me to get all my goals. With your love and patience had known how to guide me all my life, and that is why I am greatly thankful and I really glad that you are able to see how I am achieving with their help one more goal in my life.

Le dedico esta tesis a mis padres, Daniel Gracia Gómez y Rosa María De Luna Cárdenas, quienes siempre me han apoyado y me han inspirado a conseguir nuevas metas. Con su cariño y paciencia me han sabido guiar a lo largo de mi vida y por eso les estoy muy agradecido y me llena de alegría que puedan ver como estoy logrando un objetivo más en mi vida gracias a su ayuda.

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I want to thank my committee, for the time and help that had provided me. I want to thank to Dr. Douglas Timmer for his help with the statistic analysis and ideas to identify the different clusters in the analysis. To Dr. Dumitru Caruntu I would thank his contribution in research ideas and analysis. Also, I would like to thank to Dr. Emmet Tomai for his time on this project, guiding Roel in the software development for the virtual environment which was fundamental for this Thesis.

In addition, I want to thank to Roel Tijerina, who has been a fundamental part of this thesis. Roel completed extraordinary work to develop all the requirements, designing the virtual environment and making the data base to save all the required data. Roel was a key part of this project, balancing his time between school and the developing of this project. He worked really hard searching for solutions, achieving to get all the changes that the project required. I want to thank to Roel his dedication to the project and his hard work.

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CHAPTER I

INTRODUCTION

1.1 Problem Description

Virtual Reality (VR) is not a new technology, it has existed for four decades. There are several studies to improve this kind of technology, which developed such as the Cave Automatic Virtual Environments (CAVEs), holograms and head mounted displays (HMDs). These technologies have made great progress through development of both software and hardware. Considering application areas, there have been several studies to adapt VR to entertainment and for training in different disciplines, disciplines such as manufacture [1], emergency reaction situations [2], medicine [3], and undergraduate and graduate learning methods [4]. However, there is a significant lack of study at the moment for human reaction and behavior while human subjects are in a virtual environment. There are few studies on how VR stimuli works on human beings, if there are a similitudes or differences at the moment to react between men and women, or if the subjects follow a predetermined travel with their body. This lack of research is an area with good opportunities, and it can help to analyze human behavior as immersed in a virtual environment. With significant additional investigation, it may be possible to generate a standard for human reaction in virtual environments, so it could become easier to improve the hardware and software in virtual reality devices for human interaction.

1.2 Background

Ergonomics is the study of the design of work in relation to the physiological and psychological capabilities of people, and it focuses on the evaluation and design of environments, training methods and equipment to match the capabilities of users [5]. Biomechanics is the application of mechanical principles to the analysis of body part structure and movement, including speed of movements, and the body's mechanical responses to such physical forces as acceleration and of vibration [5]. The ergonomics pioneers were Frederick W. Taylor and Frank and Lilian Gilbreth. Taylor broke job tasks into elementary motions, making it easier to complete analysis for almost anybody and with his *Principles of Scientific Management* [6]. The other pioneers, Frank and Lillian Gilbreth studied the motion and "speed work" by classifying hand motions into 17 basic divisions (called *therbligs* from his last name), and they tried to eliminate or reduce all the unnecessary motions [6]. In addition, Chengular's work, explains that there exist several institutions which have ergonomics standards such as the American Society of Mechanical Engineers (ASME), Occupational Safety and Health Administration (OSHA), and the American Conference of Governmental Industrial Hygienists (ACGIH). Ergonomics and biomechanics have great importance in engineering at the moment to develop a new product, process or system, and they study the reaction, balance, and how efficient a system is for the users.

Virtual Reality (VR) has existed for four decades, and it has been evolving in different technologies. The most popular are the cave automatic virtual environments (CAVE), holograms, and head mounted display (HMDs), but there are some other kind of virtual reality environments. Merriam-Webster Dictionary defines VR as: *"an artificial environment which is experienced through sensory stimuli (such as sights and sounds) provided by a computer and in which one's* *actions partially determines what happens in the environment; also: the technology used to create or access a virtual reality"* [7]. Like every technology, at the beginning there were few alternatives and they were extremely expensive. With the growth of the entertainment and video games industry, VR technology has had a great evolution in recent years, and it is possible now for individual customers to buy some of these devices like the HMD systems, at a much lower cost due to mass production and marketing. These are some points that differentiate these technologies: the CAVE is more like a room with walls where the environment is projected; the hologram is a three-dimensional image reproduced from a pattern of interference produced by a split coherent beam of radiation on a determined space [8]; and the HMD is like a headset with glasses which lets you see the virtual reality. In the case of the CAVE and hologram, the virtual environment is shared among all, and for the HMD only the subject using the HMD is immersed in the virtual environment.

But a concept that is shared in all the VR systems is the presence in a virtual environment. The meaning of this concept is related with the *presence* with respect to the real-world experiences, and how deeply involved the user feels in the virtual environment [9]. Usoh et.al. completed an investigation that mentions that the most common method to analyze the presence in a virtual environment is by giving a questionnaire to the tested subjects, but they consider that it is necessary to make a real-life experience to verify the performance of the virtual environment with respect to presence [9]. Also, Slater et.al. mention in an investigation with a tri-dimensional chess experiment, how the self-perception in the virtual environment is important. And with this approach they define the virtual body, which is both part of the perceived environment, and represents the being that is doing the perceiving [10]. Presence in virtual environments is an important concept to consider, and it requires one to include the design of the virtual environment and how it is going to be evaluated (e.g. questionnaires, a comparison between real-life and VR experiments, or both).

1.3 Research Objectives

In this thesis, all the experiments are made with a head mounted display (HMD), which is the HTC Vive model. It is one of the best in the market at an accessible price, and there is an HTC Vive HMD system at The University of Texas Rio Grande Valley (UTRGV). The purpose of this research effort is to measure and compare the human response to stimuli in a virtual environment, more specifically the dominant and non-dominant hand trajectories are measured with time as the subject balances an object while advancing along a virtual trail where unknown obstacles suddenly appear in the test subject's way. The overall objective is to measure and compare trajectories from male and female subjects, to learn from human balance response, and with this information understand how humans respond to virtual environment stimuli, by employing the HTC Vive. This knowledge has presence in virtual environments implications, and can be confirmed with the use of an experiment with a survey. So, the principle thesis for this research is that it is possible to differentiate male and female subjects when they are balancing an object while they go on a virtual environment trail with obstacles using a statistical trajectory analysis and a survey to confirm the presence is also employed.

1.4 Organization of Thesis

This Thesis is organized by chapters, the first chapter explains the problems, gives a background and sets the objectives. The second chapter has the literature review, where published work is explained in more detail regarding how the Head Mounted Display (HMD) works, the importance of the human reaction and balance, and the tool of body motion tracking.

The work plan to provide data from experiments is provided in chapter three. The experimental procedure and methodology is explained, considering the process to create a virtual environment and the steps of the experiment. In chapter four, the data is examined and how the data from the experiments is obtained and it is displayed in tables, with the explanation from this data. For chapter five, the data from the chapter four is analyzed and discussion regarding what is observed from all the subjects who participated in the experiment, with the statistical analysis from the data collected. For the last chapter, chapter six, the conclusions from the experiment are outlined. Chapter six explains the result from the experiment, and has final observations from the investigation with recommendations for further work.

CHAPTER II

REVIEW OF LITERATURE

2.1 Virtual Reality

Virtual reality (VR) is a technology that creates a 3-D image by the design of a virtual environment with the help of a computer, and electronic devices. This virtual environment creates 3-D images, could be also created in holograms or by superimposing this environment into the real world (augmented reality). Virtual reality environments are considered as part of the visual technology cluster from smart manufacturing [11]. These environments for VR are commonly used as a computer simulation, which creates a world that appears to our senses in much the same way that we perceive the real or "physical" world [12]. This VR experience provides synthetic or artificial stimuli to one or more of the user's senses. Normally the most common substitution is the visual stimuli, and commonly supported by the aural (hearing) stimuli. On a second level, it is also common to use skin-sensation and force feedback (with special instruments) and this is referred as haptic (touch) sense. And some of the less frequently use stimuli are the vestibular (balance), olfaction (smell), and gustation (taste). It is important to consider that all the senses could be recreated with virtual stimuli, but some are harder to recreate than others. Also, it is important to consider the importance of the specific sense at the moment to recreate the stimuli for the different senses [12].

For the head-mounted display (HMD), the technologies to reproduce the virtual reality environment with all its respective stimuli is reliant on the following technologies [13]:

1. Real-time 3-D computer graphics
2. Wide-angle stereoscopic displays
3. Viewer (head) tracking
4. Hand and gesture tracking
5. Binaural sound
6. Haptic feedback
7. Voice input/output

From these technologies, the most relevant are the *real-time 3-D computer graphics, wide-angle stereoscopic displays, viewer (head) tracking*, which are mandatory, the *hand tracking and the binaural sound* are desirable, and the *haptic feedback* and *voice input/output* are technologies which are still in development and are not fundamental [13]. Thanks to the advance in all these technologies, it is possible to create virtual environments where the user can be immersed in them with all the possible stimuli. The diagram from Craig et.al in figure 2.1 illustrates how a VR system is integrated by its typical components [12].

The adoption and use of VR as a practical tool is based on the benefits that this technology adds. VR search can reduce product development times, increasing the scientific insight, improve learning, and provide entertainment, and at the same moment reduce the costs to generate the benefits mentioned. That is why the principal application fields for this technology are the virtual prototyping, simulation visualization, training and entertainment [12].

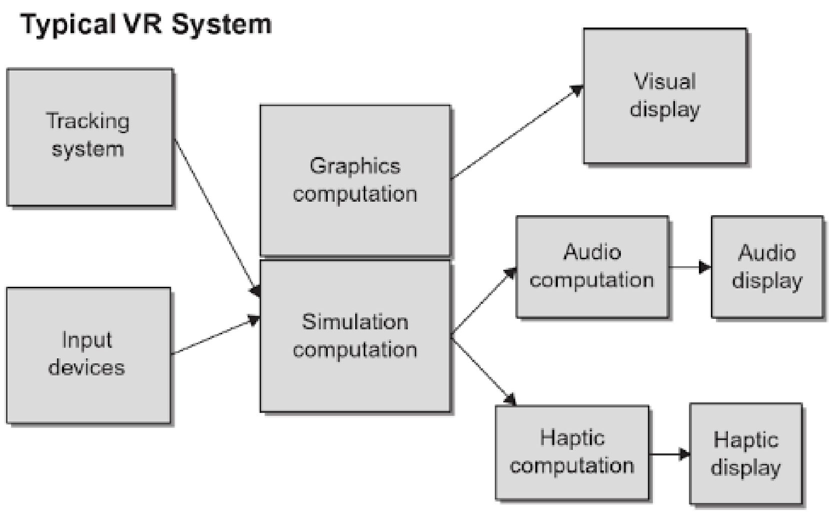


Figure2.1 Diagram illustrating how the various components are integrated in a typical VR system [12]

2.1.1 Virtual Reality and Biomechanics

Biomechanics in Virtual Reality is a field that has multiple areas to research, these study areas can be identified as:

- Biomechanics visualization
- Simulation equipment and training
- Human responses to virtual environments

These areas mentioned above can be mixed at the moment to study a specific topic, but it is possible to identify which are the areas covered in the respective investigation. All these areas help to understand the biomechanics of the human body and how technology advances impact on the users. It is important to understand the impact and responses of virtual reality technologies to set a standard, learn more about the human subjects and improve this knowledge (biomechanics visualization, equipment and response).

2.1.1.1 Biomechanics visualization

An important area for the study of biomechanics is the replication and motion visualization from the human body. This kind of research helps to understand how the body is designed while developing a user interface, where biomechanics scientists can observe and learn with a more dynamic system [14]. Engineers and scientists work on new techniques to develop virtual environments where it is possible to observe and manipulates different components from the human body, like shown in figure 2.2 from Kim et.al where they capture images from a computed tomography or, magnetic resonance, and in a separated process they capture a 2D high-speed X-ray video, to finally collect both data sources (2D for motion, 3D for shape) and mix them together in a process called 2D/3D shape matching [14].

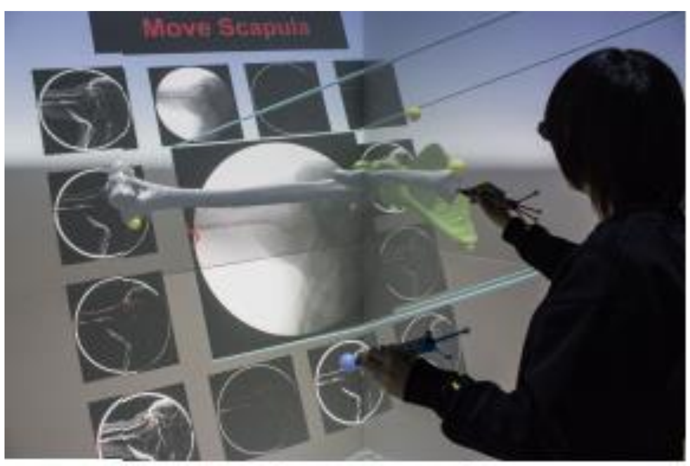


Figure 2.2 VR environment manipulating a 3D bone [14]

To understand better how biomechanics is analyzed in VR, Coffey et.al. mentions that the motion study is fundamental for science and how *"pictures of motion (e.g., the revolutionary photographs by Marey and Muybridge of galloping horses and other animals, da Vinci's detailed drawings of hydrodynamics) have factored importantly in making scientific discoveries* *possible"* [15]. Also, it is explained that the taxonomy of motion is created by the spatial and temporal data and relationship, and depending on the situation the data can be analyzed as static, animated or interactive (on both conditions: spatial and temporal). The taxonomy of motion (temporal and space conditions) is explained in figure 2.3 from Coffey et.al and helps to understand the importance of visualization. Also, Coffey et.al explain with their experiment how the subjects respond to these different combinations of virtual environments, where the subjects has to select which "bumpy disc" (top in color red and bottom in color green) collide with the other (pressing a bottom with the colors mentioned before) to determine which combination works better to visualize in a virtual environment. Figure 2.4 shows three scenarios of the experiment [15].

Visualization Design Conditions

		TIME		
		Interactive	**Animated**	**Static**
SPACE	**Interactive**	I_S,I_T -interactive camera -interactive timeline	I_S,A_T -interactive camera -animated timeline	I_S,S_T -interactive camera -multiple times in a single scene
	Animated	A_S,I_T -auto camera movement -interactive timeline	A_S,A_T -auto camera movement -animated timeline	A_S,S_T -auto camera movement -multiple times in a single scene
	Static	S_S,I_T -multiple camera views in a single scene -interactive timeline	S_S,A_T -multiple camera views in a single scene -animated timeline	S_S,S_T -multiple camera views in a single scene -multiple times in a single scene

Figure 2.3 Taxonomy of motion visualization design decisions [15].

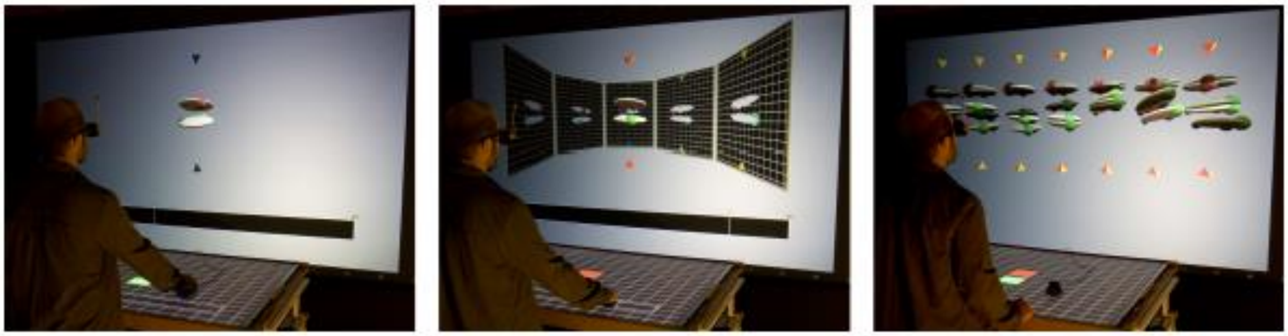


Figure 2.4 Three visualization designs to represent the "bumpy discs" motion [15].

It is important to investigate biomechanics visualization because this helps to understand and study the human body mechanical reactions. Biomechanics upgrades in VR visualization brings great advantages to medicine and standards for human security in different environments (e.g. factories, offices, construction zone). These are some of the advantages of the biomechanics visualization research area.

2.1.1.2 Simulation equipment and training

One of the most significant points in biomechanics is the creation and validation of equipment to help humans in physical activities. The use of this special equipment with VR recreates specific activities as a simulator. These kinds of simulators help to learn new activities with an interactive virtual environment. An example of these activities is swimming. Swimming is an activity that requires several pieces of equipment to simulate the complete environment, and the haptic feedback is more complex than most other activities [16]. Based on the research from Guo, this physical model achieved the goal to improve the performance of swimming teaching by using VR technology, and the physical model which was used in the investigation is shown below on figure 2.5 [16].

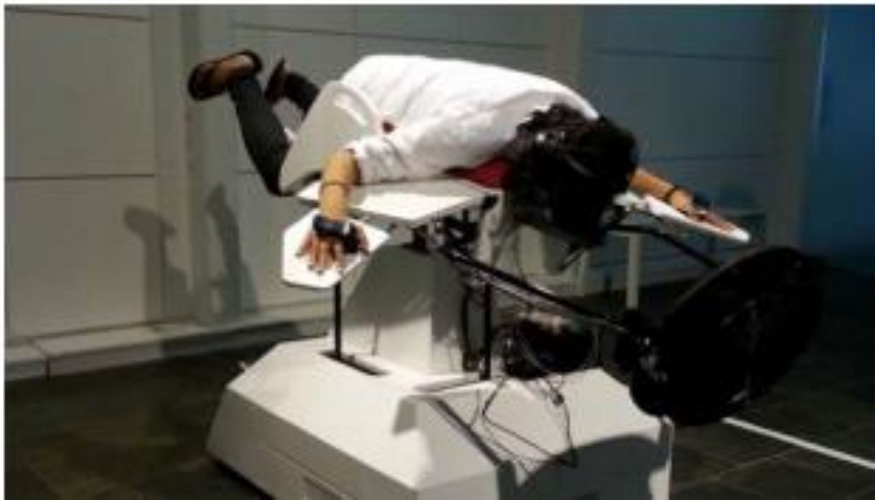
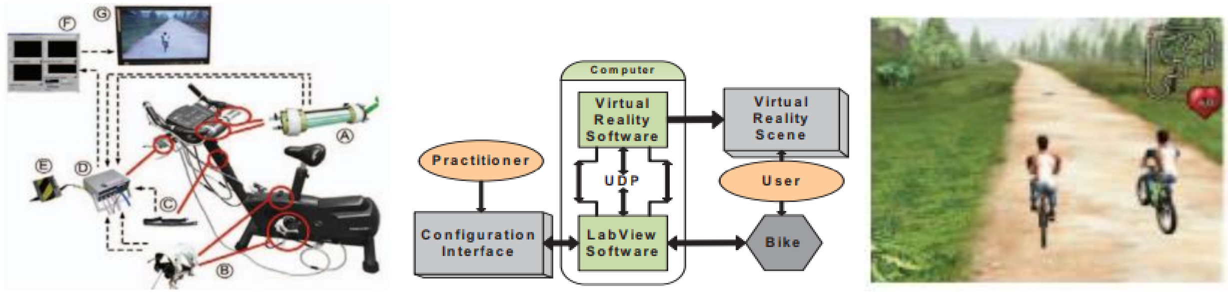


Figure 2.5 Physical model of the system to teach swimming [16]

Other important uses where biomechanics and VR work together are rehabilitation training. Ranky et.al. designed a Virtual Reality Augmented Cycling Kit (VRACK). This system is based on a stationary bike, with novel handle bars based on hydraulic pressure sensors and innovative pedals that monitor lower extremity kinetics and kinematics [17]. The subject rides in a virtual environment where the communication system is used to monitor the pedal forces (both feet are separate), handlebar forces (both hands are separate), and the heart rate while the subject is immersed on the virtual environment. The VRACK design focuses on helping people with riding asymmetry. By the use of quantitative measures and a dynamic and safe environment, it is possible to help persons with their rehabilitation [17]. In figure 2.6 from Ranky shows the bicycle system, the communication diagram and the dynamic method [17].



(a) **(b)** **(c)**

Figure 2.6 (a) VRACK model complete overview. (b) Information communication diagram. (c) The virtual rider must stay with the pace rider whilst include turning and leaning and avoiding mud puddles [17].

The use of special equipment analysis also involves sectors like vehicle handling, including response to drive a car [18], or how a pilot reacts under different circumstances in a VR flight simulator [19]. This kind of research usually includes mixed evaluation of the human response under virtual environments, considering body and eye tracking, binaural sound, and the controllers (e.g. steering wheel, pedals, joystick).

As shown in figure 2.7 from Oberhauser et.al., this kind of equipment can make the system go from an Immersive Virtual World to Simulator Research. It is possible to observe in the same figure, the fidelity, flexibility and cost change. While the cost and fidelity of the research increase with the advanced equipment, the flexibility for other kind of projects decreases [18]. This fidelity can be also observed in Eudave research, where the test subjects tried a standard driving simulation (SDS) using a 27 inch LCD monitor and an immersive driving simulation (IDS) using the Oculus Rift CV1 virtual reality headset. Even when both experiments were simulations with the driving equipment, there is a significant difference with the use of (2D) and an HMD (3D VR) [19]. Figure 2.8 from Eudave et.al. show the configuration on both experiments.

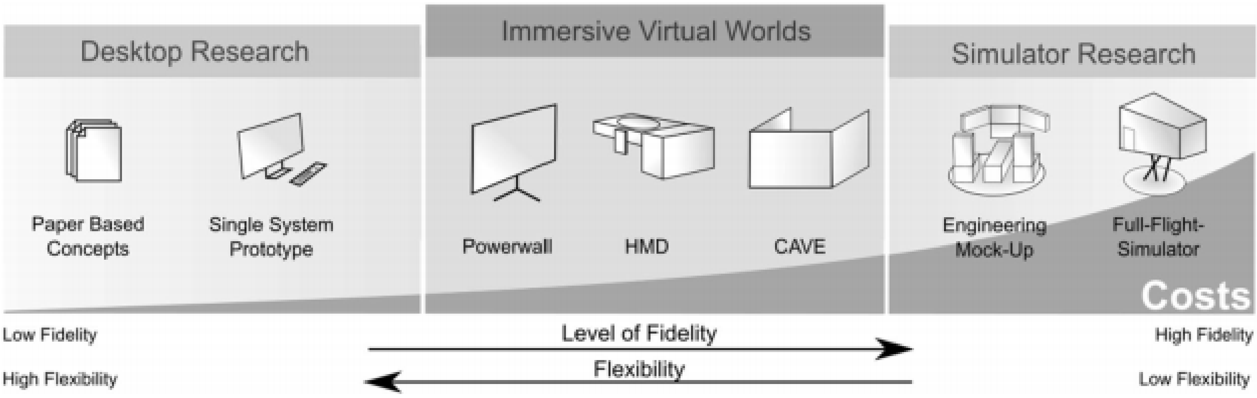


Figure 2.7 Simulator continuum for human factors research [19].

(a) **(b)**

Figure 2.8 (a) Standard driving simulation (SDS) using a 27" LCD monitor. (b) Immersive driving simulation (IDS) using the Oculus Rift CVI virtual reality headset [18].

This research area is closer to develop an Engineering Mock-Up Simulator Research than a conventional Virtual Reality Immersive Research. The extra value of the equipment brings a higher fidelity to the experiments and helps the users to feel a greater immersion into the virtual environment. While the use of this equipment limits the use of the VR equipment to the specific task (until it is separated from the external equipment), the use of simulation equipment helps the investigators analyze specific data, bringing a better understanding of relevance to the design and development of simulation equipment.

2.1.1.3 Human responses to virtual environments

An important point to consider when there is a study of ergonomics and biomechanics is the human response. This investigation area splits its effort into each of these two areas: natural response; and training for a specific response. Also, the human reaction is focused on two parts, which defines the required equipment and the experiment process. It is important to know what you want to measure, how it is possible to create an experiment, and what is required to measure the desired variable. In this kind of investigation, it is common that the tested subject wears special equipment to measure the required data (e.g. heart rate, skin conductance, tracking systems).

An example to consider is the work by Choiri et.al. [20], which recreates a stadium with humanoid models to simulate a sprint race, and this simulation has the goal to train the sprinter's concentration for real competitions. The Choiri et.al. investigation mentions that sports activities are getting more attention from the government and society, which impacts athletes by demanding better results [20]. To achieve good results, athletes must have agility and good ability in their area, but they also require strong mentality. Choiri et.al. mentions that the results of the most successful athletes are influenced by mental factors and the ability of athletes to master their psychological state. One of the elements that affects the psychological state more is concentration. This investigation focuses on creating a training process to help athletes to improve their concentration, using as a tool VR technology. To train the concentration Choiri has a table, and this table measures the concentration performance. Table 2.1 is taken from Choiri and it measures with a "Behaviorally Anchored Rating Scales" (BARS), where the subject behavior is graded on three levels. This experiment considers four indicators to determine the subject concentration, and the system automatically calculates how fast the user goes in the virtual environment, giving the subject the opportunity to train his or her concentration for a sprint race in a virtual environment [20]. Below is figure 2.9 from Choiri et.al regarding how concentration training works with the use of the VR system.

Table 2.1 Behaviorally Anchored Rating Scales Indicators for Sprinter [20]

Dimension	Indicator	Level		
		3	2	1
Focus on the task of motion	Alertness to move during	Slowly reacts to the start signal	A little slow when responding to the start signal	Exactly responds to the start signal
	Speed of running motion during the competition	Footsteps appear irregular until the finish	Footsepts appear regularly starting in the middle of the track	Have the consistency step according to the pace
	The precision of motion of the finish	Non-torso touches the finish line first	Torso and non-torso simultaneously reach the finish line	Put forward the torso when it reaches the finish line
Ability to ignore external distractions	Ability to ignore external disturbances	Pay attention to spectators and rival	Pay attention to spectators or rival opponents	Pay attention to track

(a) (b) (c)

Figure 2.9 (a) Simulation when athlete is on start position. (b) Simulation when athlete is running. (c) Tested Subject using the system [20].

Other investigations on this area work on the natural reaction of the subjects. Some investigations are related with the size-weight illusion [21], the reaction under interruptions and notifications in VR [22], and walking speeds for Virtual Walking [23]. These experiments help to understand better, human reactions under different VR circumstances (e.g. lifting a weight, physical disturbances, walking in VR). While VR is growing, it becomes more important to identify the subject's response to the different stimuli, and it is necessary to consider the virtual environment stimuli with the possible interaction with physical stimuli or objects.

The perceptual conditions have a great influence in human behavior, Heineken et.al. [21] tested the seize-weight illusion created by different perceptual conditions. In this investigation the subjects were tested by lifting cylinders (with specific sizes and weights) in three different conditions (natural reality, flat screen and HMD). Heineken et.al. show with the data that the degree of the illusion is greater in immersive conditions than with non-immersive virtual realities, where it was determined that the higher the immersion in the virtual reality, the response is more similar to the natural reality response. Figure 2.10 from the Heineken et.al. investigation shows how the test was designed with the three different procedures.

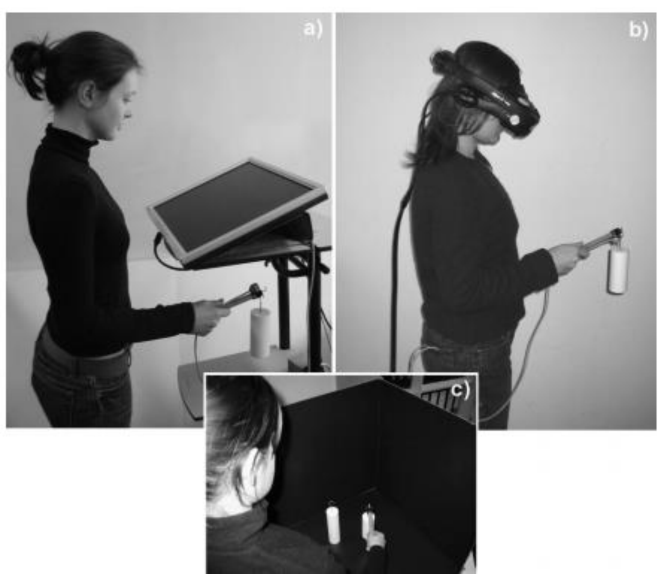


Figure 2.10 Seize-weight illusion with virtual reality [21]

Now that VR is more affordable and it is possible to have one at home, and it is important to see how the subjects react in the virtual environment with external interactions. Ghosh et.al. mentions in their research how the VR immersion disconnects the subjects from the real world [22]. But it is important to consider what can happen if the subject interact with an external situation (e.g. phone call, wandering pets, losing track of time), like it is shown below in figure 2.11 from Ghosh et.al. In this investigation, Ghosh et.al. consider these kinds of scenarios and propose different kind of countermeasures, like visual indication of a person (in the virtual environment), an audio input mentioning that a person is entering to the play area or haptic indications in the controllers [22]. Ghosh et.al. find different answers by the empirical tests and the participants, this data can help the VR designers and developers to create better notifications methods, so the subjects can interact more safely in a virtual environment.

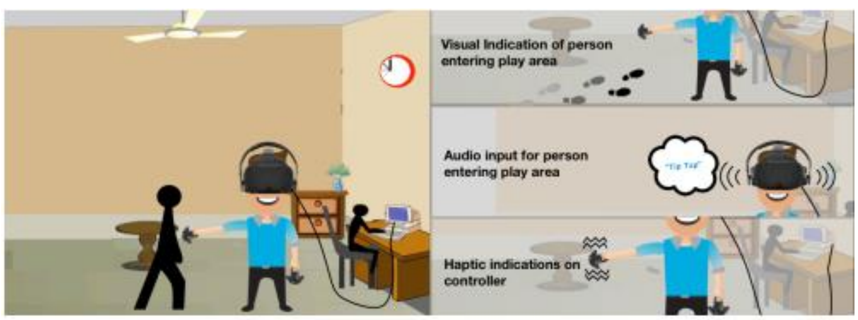


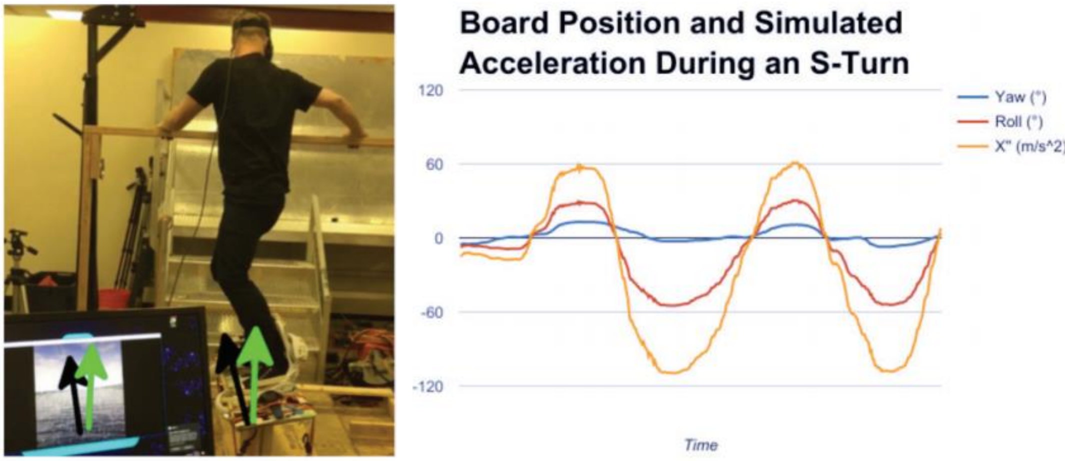
Figure 2.11 Notification Methods in VR [22]

Human locomotion in virtual environments is important at the moment to work with virtual reality. Walking comparison between a natural walking experience and the perceptual walking motion in virtual environment is a research that Nilsson et.al. study [23]. The investigation of Nilsson et.al. consider different field of views and relate it with the walking experience, and found that there exist a range of visualization where the subjects feel more natural with the walking locomotion [23].

2.2 Human Reaction; Balance and Coordination

For the industry it is necessary to analyze ergonomics because there are many human capabilities that are required for jobs. These capabilities include: reach; strength; cognitive thinking, or coordination [5]. But these capabilities are also important in daily life, and with recreational activities, such as snowboarding [24], crossing a road as a pedestrian [25], or playing some video game [26]. These three cases have different ways to evaluate the human response under the corresponding activity. It is important to study the human reaction with the VR immersion to improve the technology and to consider how humans react in virtual environments.

For training of snow board activity, Hament et.al. located the board with a constant pitch angle, which is a small downward angle similar to that found in a beginner's bunny slope. This platform has 2 degrees of freedom, which are roll and yaw, and it is possible to acquire the x value from the software. The yaw and roll values come from accelerometer and gyroscope data from an HTC Vive controller and IR sensors are plotted with the resulting lateral acceleration rendered in the virtual environment [24]. In figure 2.12 from Hament, it is possible to observe one of the tested subjects using the simulator, and how the system measures the mentioned degrees of freedom (i.e. roll, yaw, and x), and this data helps the understanding of human balance and reaction when the subject is immersed in a virtual environment snowboarding [24].



a) b)

Figure 2.12 a) User demonstrates slight roll and yaw angles; b) yaw, roll and x values [24].

Mallaro et.al. investigated is a comparison between an HMD and a CAVE, where the responses of humans are studied on an interactive pedestrian simulator [25]. For this experiment, a group of persons has to "physically cross a one-lane virtual road with continuous traffic traveling from left to right." The cars traffic has random gaps between cars, and the subjects have to watch and cross to the other side when they think the gap between cars is long enough [25]. Mallaro et.al. focuses on two main aspects of road crossing: gap selection and movement timing. The gap selection is divided in two factors: number of gaps seen, and the mean gap size taken at the moment to cross. And, for the movement timing there are four factors: standing position from the roadway, timing of entry, road crossing time, and time to spare [25]. This investigation has a different approach with the data, considering more the time to react by the observation of a certain activity (gap between car on the traffic), than coordinates or degrees of freedom (such as Hament et.al. snowboarding simulator investigation).

One of the most common use for VR technology is videogames and entertainment, that is why it is important to know the user reaction and intuition at the moment of immersion in a virtual environment. The Lee et.al. investigation works with a data glove, which is compared against the Vive controller. The data glove has bending sensors to examine which finger is bent or not, and the "MPU6050 6 -axis sensor" to detect the rotation and movement of the hand. To have an idea of the importance of this paper, figure 2.9 shows how both controllers are designed (HTC Vive and Data Glove) [26]. To verify the reaction of the subject, they play a game two times (one with the Vive controller and one with the Data Glove), in which the subject has three different situations (each of one minute), where they have to use different configurations that select with the corresponding controller. The evaluation of the subject's reaction with the controllers consist of a survey, where the criteria is based on: responsiveness, accuracy, and understandability. This criterion is answered with questions like: Did the interface reacts as well as the user intended? Did the interface perform well during the operation? And is the interface intuitive? [26]. With this survey, Lee et.al. try to define which controller reacts better and is more intuitive for the users. Figure 2.13 shows the HTC controller and the data glove.

a) **b)**

Figure 2.13 Controllers; a) HTC Vive equipment; b) Data Glove [26].

There are different ways to measure the human reaction in a virtual environment. As shown in the investigations from Hament, Mallaro and Lee, there are different ways to evaluate the human reaction when a person is immersed in virtual environments. The reaction can be analyzed by the degrees of freedom affected (e.g. x, y, z, roll, pitch, yaw), certain activities observed, a survey, or by mixing some of these options. It is important to consider the kind of experiment that is investigated to determine the criteria to evaluate for the specific investigation.

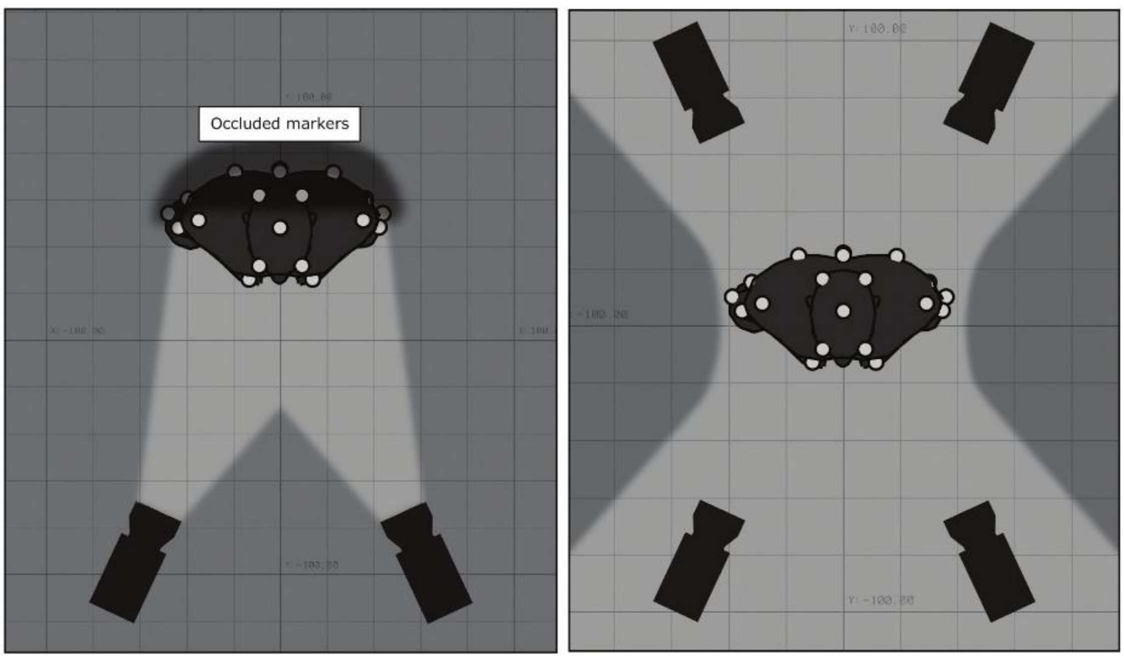
2.3 Body Motion and Tracking

Body motion and tracking has several study areas, but the most common applied is the one related to the optical motion capture technologies. Tobon defines motion capture by its own name: motion is the act of physical changing location; and capture is taken into possession, to seize, or to acquire. So, motion capture is the acquisition of movement [27]. To digitalized motion and have the opportunity to analyze it or work with it, there are several techniques, which combine the use of hardware and software to capture movement. Some of the most common motion capture systems are:

- Infrared Tracking
- Optical Motion Tracking
- Magnetic Motion Capture
- Mechanical Motion Capture

The purpose from the motion capture depends on the use of the device. One of its purposes can be to animate characters for movies and series (e.g. Gollum from Lord of the Rings, or Jake Sully from Avatar) [28]. It can be also be used to understand better the kinematics and biomechanics of the human body, like O'Brien et.al. who mentions in an investigation where the joints and body measures are analyzed [29]. Mortimer et.al. investigates how to use the capture of motion to teleoperate the dynamic of user interfaces for robotics [30]. One of the most important areas to use body tracking and motion capture is in VR systems, where the body tracking helps the engineers to design and observes mock ups in a CAVE [31], or it can help a user to select certain activities by the hand gestures while he or she is immersed in a virtual environment [32].

It is important to consider how the systems work. Most of the optical system work with cameras and markers [27]. Tobon explains how the markers can lose the contact with the cameras, and that is why, it is important to cover the most possible angles as shown in figure 2.14. The markers that are not seen by the cameras are called occluded markers, and they are not able to be considered by the software [27]. Another kind of solution (at the moment to design), is to select another kind of motion capture, such as the magnetic which consider electromagnetic fields.



a) **b)**

Figure 2.14 Optical Motion Capture: a) Person with occluded markers; b) Person with all markers visible [27].

Most of the consoles or devices that uses body motion tracking by including their own integral system. This is the case of the HTC Vive, Oculus Rift, or Kinect. But there exist other products in the market, such as Vicon, which is one of the most used in CAVE systems. It is possible to upgrade the different systems, or to generates new commands, but it is necessary to understand how the system works. It is important to consider both, signals and sensors which are involved.

In the case of the HTC Vive (VR system used in this investigation), the system has two lighthouses (tracking base stations), which covers a 360-degree play area, have wireless syncing, fits standard threaded mounting points, and cover a room-scale of 6’6” x 5’ minimal room size to a 16’4” maximum between base stations [33]. The headset and controllers have several sensors inside them, these sensors are captured by the lighthouses. These lighthouses are two small cubes that emit light and scan the room vertically and horizontally. Every time the lighthouse emits the light, the sensors from the headset and the controllers are activated and the lighthouse measures the time that it takes to be activated, and by calculating the position and orientation of the sensor when it was activated, the lighthouse is able to track the headset and controllers with six degrees of freedom (i.e. x, y, z, roll, pitch and yaw) [34].

2.4 Virtual Reality Presence

Slater et.al. mentions that presence can be defined by the subjects as their sense of “being there,” referring as the sensation of realism in a virtual environment [35]. This definition can be extended as the subject’s experience in the virtual environment more as the present reality, than the real world where the experiment is taking place, and the user feels immersed in an actual place, instead of just watching images [35]. It is important to consider the perception and stimuli (e.g. aural, haptic, vestibular) from the environment, and the subject’s existence in the actual virtual environment (the self-existence in a virtual environment is known with the name of Virtual Body). To feel more immersed in a virtual environment it is possible to add different feedback actuators, but some are harder to recreate than others, and it is important to consider which are the most significant for the experiment. In addition, it is also important to consider the laws of physics (e.g. gravity, objects collisions), and the possibility of virtual actuators responding to the subject [35].

VR presence is one of the most important subjects at the moment to consider for VR investigations. It is important because it is always indirectly related to the experiment's reliability. That is why it is important to design virtual environments that fit correctly with the requirements of the investigation. Some authors like Slater et.al. mention that it is important to test the results from the VR experiment with a physical (real life) experiment, or at least to make a survey with questions related to the VR experience sensation [10]. This comparison has the goal of evaluating the actual response from the subjects, considering the depth of presence when in the virtual environment. Also, Barfield et.al. mentions that performance and presence have a strong relationship, and it is necessary to develop more research effects to define how to measure the presence and what are its limits [36].

There are few methods to measure presence. The two most common are to make the experiment in VR and real life to compare results, and to apply a survey. Comparing experiments would be the most precisely to confirm the depth of the presence for the user when he or she goes into the virtual environment. The problem is that it is not always easy to replicate the experiment in real life (VR is very often used to investigate circumstances that are not easy to replicate or that are very dangerous or expensive). The option of the survey is easier to apply, but it does not have the reliability that an experiment comparison would have. For this investigation, a survey is applied to all the participants after the subject is reintegrated to the real environment, and this survey is compared with their paths in the virtual environment to confirm or refute how immersed they were at the moment in the virtual environment.

CHAPTER III

PROCEDURE AND METHODOLOGY

3.1 Virtual Reality Environment

Virtual environments are a fundamental part of any VR project. What is desired is a virtual environment where the human subject is so immersed in the created environment that he or she believes the environment is real. Considering the importance of the environment, it was necessary to have the support of a Computer Science Team, which develop the environment with the corresponding programming. The equipment used for this project are: a computer to create the program and save the corresponding data; a head mounted display (HMD) to show the track and where the subject has visual stimuli; two controllers, one to navigate inside the virtual environment (with the dominant hand) and a second one to balance a virtual ball which is on a plate (with non-dominant hand); tracking system, two boxes which track the HMD and the two controllers. The HMD, controllers and tracking system are the original system from HTC Vive.

Using the HTC Vive, this project studies human balance and coordination. This investigation measures the balance and coordination of the head, dominant hand and non-dominant hand, by tracking the hand in six degrees-of-freedom (DOF): x, y, z, pitch, roll, and yaw over time. The body tracking from each test subject draws three paths on the six dimensions where data is saved on the memory and is compared at evaluation. The subject navigates by moving the dominant hand on a track, and this track is on an open area which has curves and land relief. A picture of how the track looks is shown in figure 3.1. With the non-dominant hand, the subject balances a ball which is supported on a plate, as is shown in figure 3.2. Considering the goal of studying the balance and coordination of the subject, on the track three unknown obstacles appear to generate a dramatic and strong stimulus, which are separated based on a similar space along the test subject's path. These stimuli are:

1. An explosion on the track
2. Meteors coming from the left side
3. Bird flock crossing through the path

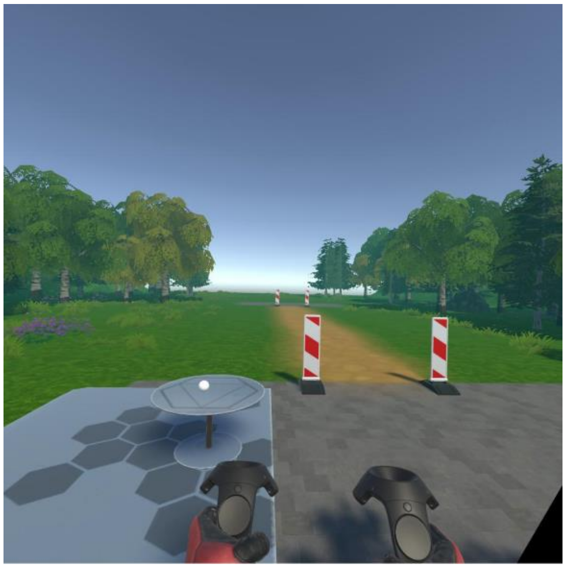


Figure 3.1 Virtual Environment.

Figure 3.2 Ball on plate to balance.

These unknown obstacles for the subject are shown in figure 3.3, and they have the goal of generating an impact on the subject. It is expected that the subject should react with compensating motion. With this impact, it should be possible to observe, whether there is a disturbance to the smooth path from the body tracking data, caused by these stimuli. It is possible to observe three paths from the body tracking, one from the HMD and two from controllers (one for each control). The results are statistically analyzed considering the six DOF on a 3D environment.

a) b) c)

Figure 3.3 Stimuli Assets. a) explosion; b) meteors; c) bird

3.2 Experiment Methodology

Since the purpose of this research effort is to measure and compare the human response to stimuli in a virtual environment, the experimental work is conducted in a virtual reality environment where an HTC Vive HMD system is employed. The experiment methodology is as follows:

- Give the subject the consent form and questionnaire, and obtain a signed form.
- Determine dominant and non-dominant hand.
- Give a VR tutorial to the subject.
- Test the subject on the virtual environment.

- The subject has time for reintegration to the daily activities.
- Provide a survey about the presence in the experiment.

These six steps represent the basic experimental methodology.

3.2.1 Consent Form and Questionnaire

The research team provides a synopsis of the study to the test subject, request that the test subject read and sign the consent form, and asks the subject to complete a brief questionnaire. The research team member also answers any questions that the test subject may have. The subject can have as much time as they require or want to complete and sign the consent form. If the consent form and the questionnaire are not completely filled out and signed, the subject can not continue with experimentation. This Consent Form and Questionnaire are approved by the Internal Review Board (IRB) of the University of Texas Rio Grande Valley (UTRGV), and they are shown in Appendix A. Also, the recruitment flyer and protocols are approved by the IRB of UTRGV and are attached in Appendix B1, B2 and B3.

3.2.2 Determine dominant and non-dominant hand

To determine which control is used by each hand, it is necessary to employ a survey, which is also approved by the IRB at UTRGV. The survey provides which is the dominant and which is the non-dominant hand for each subject. This is the Edinburgh Handedness Questionnaire and it is formulated with questions where the subject answers which hand they prefer to use for each activity (e.g. writing, using scissors, using a key to unlock a door), or if there is no preference at all. With this information the controllers are programmed to work for one hand as the dominant hand or vice versa. This configuration helps the user to feel more natural from the moment they are immersed in the virtual environment.

3.2.3 Tutorial

An orientation using the HTC Vive equipment is conducted, where the subject uses the system with all the equipment and learns how to use the hand-held wands to navigate in a virtual environment. This training is fundamental to preparing the subject. The central idea is to familiarize the subject with the equipment, but without letting the subject know the actual experiment. When the subject completes the tutorial, he or she knows how to manipulate the HTC Vive in the virtual environment, and he or she is capable of traveling on the virtual trail. This tutorial is provided in a different environment than the test track, and the subject is able to learn how to use the controllers, how to balance the ball on the plate, and how to reset the ball on the plate in case the ball falls to the floor.

3.2.4 Research Test

As with the tutorial, the test subject is located in a scene in a virtual world while using the HTC Vive system equipment. The test subject navigates through the virtual environment where there is a marked trail with undisclosed obstacles. The undisclosed obstacles are: a rock coming unexpectedly in front of the subject; a bird flock coming from one side; an explosion next to the trail. Based on position along the virtual world trail, obstacle which expect to create a disturbance on the subject's trajectory appear, forcing the test subject to balance the virtual ball on the plate which is controlled with the subject's non-dominant hand. If the test subject puts his or her non-dominant hand in a horizontal position like it is shown below in figure 3.4, the virtual ball falls from the plate to the floor, just like in real life, but the ball can be reset to the plate using the button shown in figure 3.4 from the dominant hand controller. For experimental expediency, the ball can be reset on the plate with the click on the controller, instead of grabbing it from the floor. This avoids having the subject stop every time the ball falls. This is because the head and both hands are being tracked to collect the data to generate the three different paths. If the ball had to be replaced, the tracks wounded be difficult to interpret. The virtual paths from all the experiment participants are gathered, and this data together is used to generate clusters to identify statistical similitudes or differences.

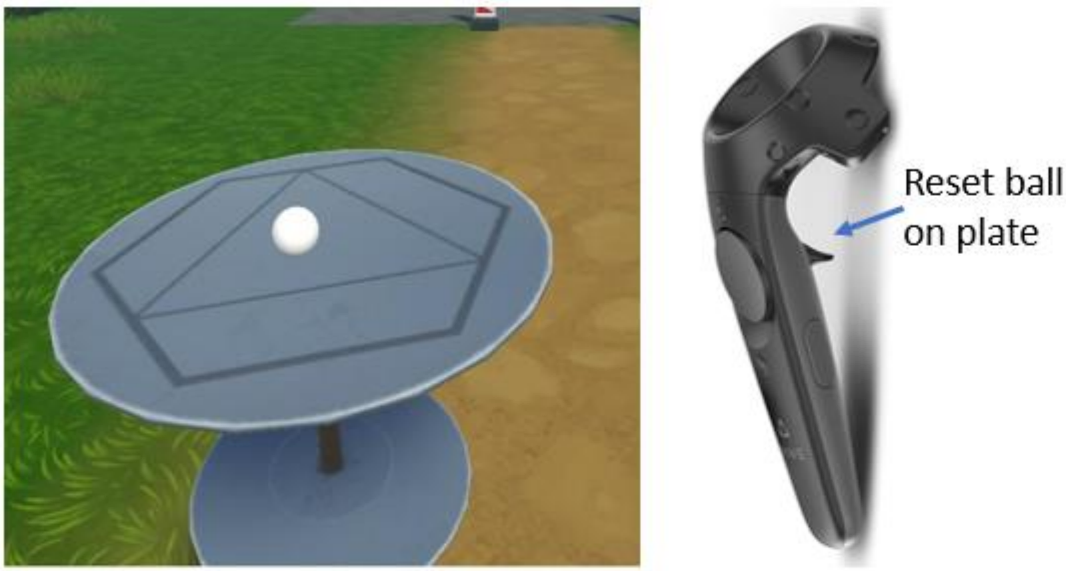


Figure 3.4 Ball falls to the floor and it is reset back to the plate.

3.2.5 Subject Reintegration

The use of VR in a prolongated time can make the eyes tired or alter other human senses. For this reason, it is important to have a reintegration time to the real world. After the test, the test subject sits quietly and regains their real-world perspective. It takes around 10 to 15 minutes to manage the human sensory system to ensure that the human subject is back to normal and that they are able to perform normal activity. It is important to require this reintegration time to avoid any kind of accidents after the test (e.g. nausea while walking, disorientation, possible fall).

3.2.6 Presence Survey

After the subject reintegration, he or she is asked to respond to a survey. This survey focuses on measuring the VR presence, which means how immersed the subject felt in the virtual environment. With this survey it is possible to measure if the subject really feels that the virtual environment is real, or how real is the perception. The Presence Survey is approved by the UTRGV IRB, and it is attached in Appendix C.

3.3 Statistical Analysis.

After saving and gathering all the data from the degrees of freedom (x, y, z, roll, pitch, yaw) over the time, it is necessary to organize it and analyze it. The information from all the participants is saved in different folders, to avoid any kind of confusions with the information. And there is a master file with the collected data from all the participants, this data is separated by male and female, and it is the one statistically analyzed.

To compare the balance and coordination from both genders, this research focused on the time to complete the track, the time it takes to reset the ball (if the ball is dropped), the effective balancing time during the experiment, how many times the subject drops the ball, the ball speed and the survey score. These variables are analyzed by contingency tables, t test, correlation and phase planes. Chapter IV has a deeper explanation on the parameters, variables and methods used for this investigation.

CHAPTER IV

EXPERIMENT DATA

4.1 Experiment specifications and variables

To analyze this study is important to control different factors and collect the data from different variables. In this case the environment is controlled and the data from the headset and controllers are collected. The environment exists as a path in a forest, this path is 190m long with 8 curves and a width of 4m, and figure 4.1 represents the route of the path. An important fact from the path is that the virtual environment works with a left-hand system, as it is shown in figure 4.2. The plate that is used to balance the ball has a diameter of 0.31m (31cm) and the ball has a diameter of 0.03m (3cm). Figure 4.3 below displays the measures.

Figure 4.1 Path Route.

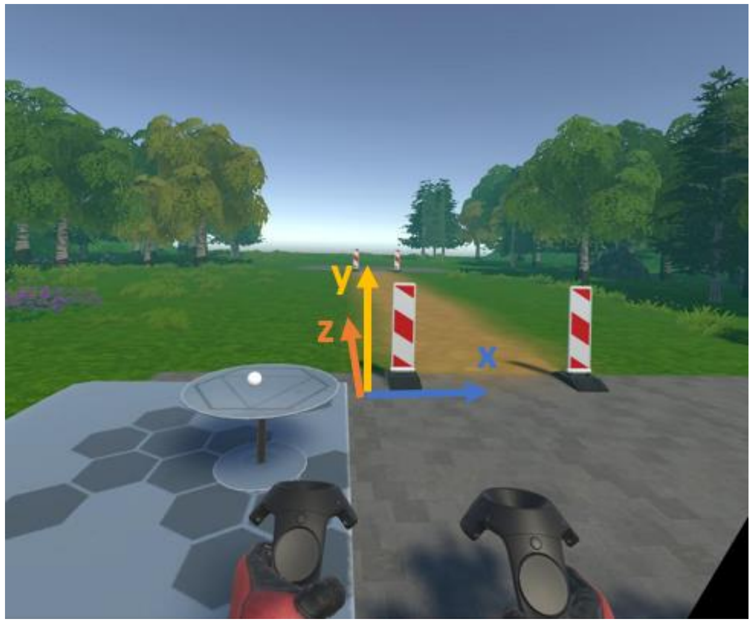


Figure 4.2 Left-Hand System in the Virtual Environment.

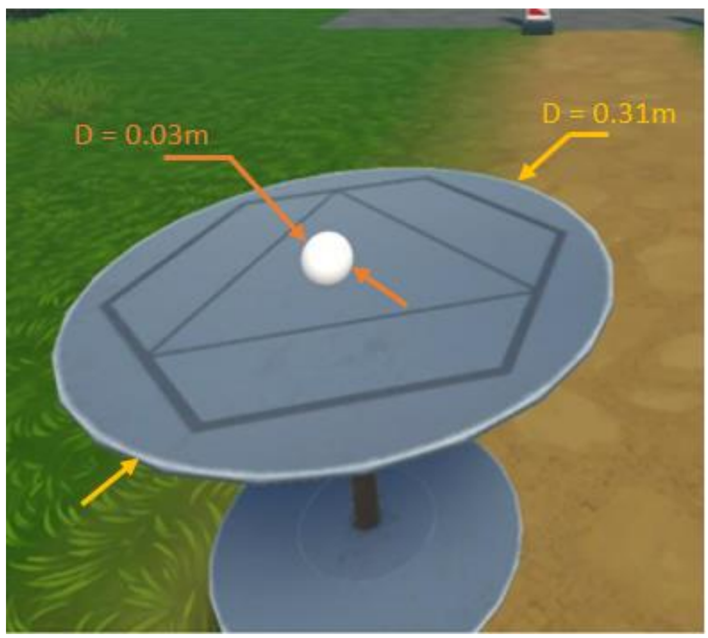


Figure 4.3 Plate and Ball Measurements.

Every time a subject participates in the experiments a new file is created with the information from the subject. This information has data as values from the different variables that the subject gathered along the path. These variables are the track time, how many times the ball and the plate were dropped, at what time the events happened, the ball displacement on the plate, and the position on the six degrees of freedom (DOF) from the headset, and the controllers (both right and left). From these variables it is possible to get some indirect variables such as the time to reset the ball, the effective balancing time of the ball, the ball speed, the delta between the controllers and the headset, and the speed of the headset and the controllers. And, with the mark in the specific events it is possible to analyze periods of time around specific events.

This thesis is focused on the study of the human balance and coordination when a subject is in a virtual environment. This means that some variables do not have a significant relevance in the study, that is why the variables that are considered are:

- Time to complete the path (Track Time)
- Time to Reset the Ball
- Effective Time Balancing the Ball (Balancing Time)
- How many times the Ball is Dropped (Ball Drop)
- Ball Speed
- Survey Score

With the variables mentioned above, this research effort looks for significant differences between male and female subjects using statistical methods. The methods used in this thesis are the contingency table (with Chi-Square), the T-Test and the correlation between variables. A variable that is also considered with the data collected from the experiment is the presence from the subjects (evaluated with a survey), which is potentially related to the other variables by a relationship between the presence and the balance and coordination from the different subjects.

4.2 Classification Methods

The management and use of the data collected is one of the most important steps to demonstrate and affirm or refute hypotheses. That is why it is necessary to use statistical methods to verify the hypotheses. For this body of research, the methods used are the Contingency Table with the use of Chi-Square Test (X^2), the T-Test and Correlation. With the use of these tools the different data is classified, and it is searched to show a significant difference between the male and female subjects.

4.2.1. Contingency Table (Chi-Square)

Ott et.al. mentions that contingency tables are tabulations arranged in cross, and their function is to test for comparing proportions [37]. Ott et.al. explain that these tables work to identify if there is a dependence of the variables, which means that one variable has some value for predicting the other [37]. These tables are organized with the possible values of one variable on the rows and the possible values of the other variable determine the columns, and they show the probability of each combination in the arrangement of row *i*, and column *j* as π_{ij} [37].

To verify the independence of the variables it is necessary to set a null hypothesis (H_0), and to approve or reject the null hypothesis. With this method, the estimate for the expected value is required, and with these values it is possible to make the test statistic, X^2 [37]. The null hypothesis for this X^2 test is the independence between variables and the estimated expected value is shown in formula 4.1 and the test statistic is shown in 4.2 [37].

$$\hat{E}_{ij} = n\,\hat{\pi}_{ij} = n\frac{(n_{i.})}{n}\frac{(n_{.j})}{n} = \frac{(n_{i.})(n_{.j})}{n} \tag{4.1}$$

Where Ott et.al. explains that the row total is multiplied by the column total, and this value is divided by the grand total to get each of the values of the new arrangement [37].

$$X^2 = \sum_{i,j}(n_{ij} - \hat{E}_{ij})^2/\hat{E}_{ij} \tag{4.2}$$

This test is the sum of the square of the observed value minus the expected value, and this value is divided by the expected value [37]. Finally, this value is compared to the chi-square. distribution table (X^2_α) to approve or reject the null hypothesis, and the H_0 is rejected if $X^2 > X^2_\alpha$, where X^2_α represents an area α in a X^2 distribution with (r-1)(c-1) for the degrees of freedom of the distribution; r = number of rows, c = number of columns [37].

4.2.2. T-Test

The T-Test was created by W. S. Gosset, who invented this statistical test when he was working as a chemist in Guinness Breweries. He was not able to use his name for this study, so he published his study under the name of Student, that is why it is called the Student's t distribution, or t test [37]. This kind of test is used when it is not possible to get a large sample size to reach conclusions. That is why formula 4.3 is used as the test statistic the standard deviation (σ) should be replaced by s for small sample sizes as is shown in formula 4.4 [37].

$$z = \frac{\bar{y}-\mu_0}{\sigma/\sqrt{n}} \quad (4.3)$$

$$t = \frac{\bar{y}-\mu_0}{s/\sqrt{n}} \quad (4.4)$$

Ott et.al. mentions that the t test can be analyzed in two different ways, when the variance (σ^2) is known and when it is unknown [37]. For that reason, it is necessary to identify if the variances are equal or unequal before doing the t-test, and this is analyzed with the two-variance method. This is a statistical test which compares σ_1^2 and σ_2^2 by the use of s_1^2/ s_1^2[37]. And Ott et.al. mentions that in this analysis when $\sigma_1^2 = \sigma_2^2$, or $\sigma_1^2 /\sigma_2^2 = 1$ and s_1^2 /s_2^2 follows an F distribution, with $df_1 = n_1 - 1$ and $df_2 = n_2$ [37]. Using the two-variance analysis mentioned above, it is possible to identify if the variance is equal in case that $\sigma_1^2 /\sigma_2^2 = 1$ and s_1^2 /s_2^2 follows an F distribution, and that it is unequal in any other case [37].

When the variance is identified, it is possible to do the t test, and depending on whether the variance is equal or unequal. In case that the variance from both variables are equal, the statistical t test formula for independence is the one mentioned in formula 4.5 [37]. But if the variances from the variables are unequal, the formula 4.6 for statistical t test for independent samples and unequal variances is the one that is used [37]. To identify if the variables are independent from each other and if it is possible to identify them, there exists three different hypotheses, which are linked to the mean value (μ) and are show below.

$$t = \frac{(\bar{y}_1 - \bar{y}_2) - D_0}{s_p\sqrt{\frac{1}{n_1} + \frac{1}{n_2}}} \tag{4.5}$$

$$t = \frac{(\bar{y}_1 - \bar{y}_2) - D_0}{\sqrt{\frac{{s_1}^2}{n_1} + \frac{{s_2}^2}{n_2}}} \tag{4.6}$$

Hypotheses:

Case 1. H_0: $\mu_1 - \mu_0 <= D_0$ vs. H_a: $\mu_1 - \mu_0 > D_0$

Case 2. H_0: $\mu_1 - \mu_0 >= D_0$ vs. H_a: $\mu_1 - \mu_0 < D_0$

Case 3. H_0: $\mu_1 - \mu_0 = D_0$ vs. H_a: $\mu_1 - \mu_0 \neq D_0$

Where D_0 is a specified value, it is often 0.

The hypotheses are the same for both cases (i.e. equal and unequal variances), and this research is focused on case 3, where male subjects are compared against female subjects. This comparison is analyzed with formulas 4.5 and 4.6 shown above depending on the observed data from each analysis, and the hypothesis is rejected if $|t| >= t_{\alpha/2}$. To affirm a hypothesis this research is focused on finding a p-value of .05 [37].

4.2.3. Correlation

Correlation is a measure that generates a coefficient, which Ott et.al. relates with the strength of the linear relation between the axis x and y from a plot [37]. The stronger a correlation coefficient is, the better that x can predict y [37]. The correlation is computed by using the formula 4.7 that is shown below, given *n* pairs of observations (x_i, y_i) [37]. Also, the formulas for S_{xy}, S_{xx}, and S_{yy} are provided in formulas 4.8, 4.9, and 4.10 [37].

$$r_{yx} = \frac{\sum(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{S_{xx}S_{yy}}} \tag{4.7}$$

$$S_{xy} = \sum_i (x_i - \bar{x})(y_i - \bar{y}) \tag{4.8}$$

$$S_{xx} = \sum_i (x_i - \bar{x})^2 \tag{4.9}$$

$$S_{yy} = \sum_i (y_i - \bar{y})^2 \tag{4.10}$$

The correlation coefficient from r_{yx} is a positive number if y tends to increase as x increases. On other hand r_{yx} is negative then y tends to decrease as x increases, and for the last condition r_{yx} is zero where there is either no relation between changes in x and changes in y, or there is a nonlinear relation such as patterns of increase and decrease in y as x increases that cancel each other [37]. For this study, the minimum value to consider a significance correlation in a positive coefficient is 0.5, and in case of a negative correlation, the maximum coefficient to consider a significance correlation is -0.5.

4.2.4. Phase Plane

Beuter et.al. mentions that the phase plane is an analysis method for dynamical systems, where the variables are plotted against their time derivatives. [38]. In their study, Beuter et.al. used the phase plane because it contains the complete information about the dynamics of the studied motion, based on the displacement and velocity [38]. The phase plane helps to create a model for an object's movement, and it is visually easy to detect if there are any disturbances from the original pattern. The displacement is represented with X and the velocity with $\dot{X}$. This method had been used to represent the movement shape of different objects or body parts like in the research from Beuter et.al., where they studied and modeled the motion of a leg [38].

4.3 Experiment Data Tables

As it was explained before, the subjects that participated in the experiment were students from The University of Texas Rio Grande Valley (UTRGV). The total students who participated were 71 students, with 35 male students and 36 female students. From the 35 male students there were 5 outliers, and this made the male population to have 30 effective subjects for the research. With the female students from a total of 36 subjects, there were of 6 outliers, which made an effective subject population of 30 from the female students. Below are shown the gathered data from the effective 60 subjects (i.e. 30 male and 30 female with male and female outlier removed). This data shows the score from the presence survey, the score for the gamer survey, the score for the difficulty balancing the ball, the time in the track in seconds, the average time that it took the subjects to reset the ball when it was dropped, the effective balancing time, the score of dropping the ball, the ball speed shown in meters per second.

In virtual reality (VR), presence is a word which defines how deep a subject is immersed into a virtual environment. Presence helps the subject to feel that the virtual experience is more real. There exists research papers on this area. The survey that is used in this thesis is based on the survey that Slater et.al. use in their investigation on presence in virtual environments [35]. This survey has 6 questions and each question has seven levels to determine presence for the corresponding question. The survey is in Appendix C [35]. To calculate the presence of each subject, Slater et.al. just added all the values from the survey and obtained a final score for the presence, having a maximum value of 42 [35]. In table 4.1 below the values from the male and female subjects who participated in the experiment are shown.

Table 4.1 Presence Survey Score [score]

Male					Female				
34	38	33	33	38	37	35	34	33	34
34	38	38	14	31	40	21	32	28	33
27	12	42	24	33	27	32	29	32	24
9	20	24	36	34	10	38	34	29	30
35	32	27	37	27	36	41	36	42	28
29	22	41	31	42	33	42	37	32	37

To get a better idea of the subjects' behavior in the virtual environment and their performance, the subjects were asked about their habit of playing videogames. In this survey a Likert scale is used, where seven represents maximum familiarity with videogames and one represents the minimum familiarity. This survey is analyzed with other variables to determine if there is a correlation between their habit to play videogames and the rest of the variables, and the value from this survey is shown in table 4.2.

Table 4.2 Gamer Survey [score]

Male					Female				
2	7	7	5	6	1	1	6	4	7
3	6	5	5	5	5	2	1	4	5
5	6	5	5	1	7	2	1	1	6
5	7	7	7	6	2	2	3	2	1
7	7	5	7	3	1	1	1	1	2
2	5	5	6	7	2	1	3	2	3

One of the most relevant factors in this study is the ability to balance the ball and to thereby, verify the coordination of the subjects. To have a better idea of the subjects feeling in this area, they were asked to answer how hard they felt that it was to balance the ball. This information is also used as a correlation material, to verify their performance and how they felt in the virtual environment. In this survey the Likert scale is also used, where one is the maximum comfort balancing the plate and ball, and seven is the score which represents that it was difficult to balance the plate and the ball. The answers from the subjects are shown in table 4.3

Table 4.3 Difficulty to Balance the Ball Survey [score]

Male					Female				
2	3	1	6	4	5	2	2	7	4
2	2	5	5	3	6	7	5	4	3
4	3	7	3	2	2	5	6	7	2
4	5	1	2	5	4	4	5	3	4
6	4	6	3	5	5	4	2	5	4
2	1	5	2	6	4	6	4	4	6

The track time is the total time that a subject takes to complete the route. The speed of the walk is the same for all the subjects, but there are different track times because some subjects drop the ball more or less, and that is one of the factors that make the subject stop. Other factors are how they are balancing the ball, their presence in the environment (making them stop in the stimuli events), and their ability to follow the path curves. All these factors affect the track time, and this variable is analyzed with the t test and in correlation with the different surveys. In Table 4.4 the values for male and female subjects for the track time are shown.

Table 4.4 Track Time [seconds]

Male					Female				
407.777	274.711	253.8	275.2112	300.411	300.9444	252.667	293.3777	266.8	257.5667
245.21	252.255	272.9556	397.4778	321.2889	300.022	333.266	297.4222	391.233	254.4889
246.55	292.6555	264.445	303.8778	361.0556	270.3	269.0445	278.3778	373.0445	281.1
319.544	284.4889	287.98	229.9778	313.6223	312.944	283.9	339.2889	258.2667	272.7
273.344	360.733	384.8	348.222	237.7889	421.6778	238.7667	327.7889	319.9889	295.2667
255.6889	312.4778	293.0889	372.2112	269.7556	354.22	323.1445	277.3667	285.8223	301.6667

Another variable that is analyzed is the time to reset the ball when it has been dropped. This variable is set by the mean value that it takes to reset the ball from one subject considering all the times that he or she may drop the ball during the experiment. In the case that the subject does not dropped the ball, it is considered as zero. Below in Table 4.5 are shown the times to reset the ball values.

Table 4.5 Time to Reset Ball [seconds]

Male				
4.54	3.511	1.077	2.34	7.441
0	3.244	4.6815	1.9695	2.8
0	4.2847	0	3.4689	4.0866
4.283	3.7814	0	9.6805	9.5666
3.203	6.655	14.86	2.446688	3.5666
5.021	0	2.51	5.4418	7.19166

Female				
2.02	54.3556	18.87778	9.7111	0
2.71	1.57	2.2045	2.9629	1.413863
0	2.9778	3.0222	3.9133	0.07127
1.732	8.4055	1.3464	9.174	1.5778
2.183	3.0224	10.7	2.2788	1.86
9.52	12.9809	2.4778	4.19365	2.66

There is not a direct factor to check the actual balancing time of the ball, but it is possible to get this information from the last two variables. Consider the total time that it takes to a subject to complete the path and the time that the ball was not on the plate (time to reset the ball). It is possible to get the actual effective time when the ball was balanced. This variable is obtained by subtracting the total time to reset the ball (that data is also known) from the total time to complete the track. Formula 4.11 shows, in the case that the subject did not drop the ball, the effective time that the subject balanced the ball is equal to the total track time, because the subject was able to balance the ball on the plate for the complete route. The data from this variable is shown in Table 4.6, for both male and female subjects.

$$Time\ balancing\ ball = (total\ track\ time) - (total\ time\ to\ reset\ the\ ball) \quad (4.11)$$

Table 4.6 Balancing Time [seconds]

Male				
398.689	267.6889	252.722	247.089	226.0002
245.21	242.522	258.911	360.055	318.4889
246.55	258.377	264.445	286.533	340.622
276.711	261.8	287.98	191.2556	275.3556
263.733	340.7667	310.4667	335.99	234.223
210.5	312.4778	245.221	279.6999	240.9889

Female				
268.61	198.3111	274.4999	257.0889	257.5667
261.97	296.999	248.9222	364.5667	248.8335
270.3	239.2666	248.1556	314.3447	276.1111
299.0887	267.089	324.477	230.7444	267.9667
404.211	217.611	317.0889	297.2001	282.2111
306.62	232.278	274.889	256.4667	274.9999

One of the most important variables in this research is to observe how many times the subjects drops the ball during the experiment. This variable helps to have a better idea of the subject's balance and coordination at the moment in a virtual environment. This data can be counted for each subject, and it is possible to analyze this information with the contingency tables and with the t test. Also, the correlation from this variable is one of the most important for this research, because it relates how the subjects felt in the virtual environment and the subjects' performance. In case that the subject did not drop the ball during the route, the drop ball value is zero. Table 4.7 presents the data from all the subjects, showing the times that the ball was dropped in the complete path and in the sum of the three specific events which were used to surprise the subject.

Table 4.7 Ball Drop [score]

a) Complete Path

Male				
2	2	1	12	10
0	3	3	19	1
0	8	0	5	5
10	6	0	4	4
3	3	5	5	1
9	0	19	17	4

Female				
16	1	1	1	0
14	23	22	9	4
0	10	10	15	7
8	2	11	3	3
8	7	1	10	7
5	7	1	7	10

b) Events

Male				
0	0	0	2	2
0	0	0	2	0
0	0	0	1	2
0	1	0	0	0
2	1	0	0	0
3	0	2	2	1

Female				
2	1	1	0	0
1	4	6	1	2
0	1	1	3	0
3	0	1	1	1
2	2	0	3	1
1	2	1	1	2

The data gathered from the HTC Vive shows the ball position on the plate, and the HTC Vive monitors the position every 0.0111084 seconds. Considering the ball position change and the monitored time it is possible to get the actual speed of the ball using the formula for velocity $v = (x_2-x_1)/\Delta t$. In table 4.8 is shown the average speed of the ball for all subjects during the complete route. As an observation, when the subject drops the ball from the plate, it takes a value of -0.01, and this value causes a jump in the computed speed values, giving a much bigger value than the average speed. This effect also happens at the moment the ball is reset. These two scenarios create outliers in the ball speed. What is done to control this effect is that these two values are adjusted to zero (value that it takes the ball, because it is without change until the ball is reset), and it does not create a significant change because it affects two outliers values in thousands of values. Table 4.8 shows the average speed and delta speed of the ball for male and female subjects.

Table 4.8 Ball Speed

c) Average [meters/second]

Male				
0.00051	0.00109	0.000555	0.007673	0.005282
0.000148	0.002358	0.001667	0.008365	0.00016
0.000145	0.004392	1.02E-05	0.002898	0.001806
0.004434	0.002697	0.000264	0.00244	0.001897
0.002024	0.001005	0.001853	0.002315	0.000383
0.00449	0.000064	0.010666	0.005461	0.001667

Female				
0.008446	0.000294	0.000501	0.000115	0.000218
0.00778	0.0102	0.011216	0.003834	0.002504
0.000174	0.00525	0.005513	0.006756	0.003763
0.003905	0.00097	0.005604	0.001446	0.001923
0.003431	0.004125	0.000233	0.005368	0.004319
0.002001	0.003025	0.000595	0.004422	0.00522

d) Delta [meters/second]

Male				
1.9414	1.0392	0.8927	1.12001	1.01035
1.0715	0.79174	0.411297	0.395376	0.64593
0.65837	0.685573	0.653678	1.007743	3.3891
1.2991	1.2386	0.692483	0.86015	2.423378
0.58738	1.4871	1.3957	1.3497	1.486686
2.2957	0.671253	1.24	2.9366	3.11855

Female				
1.008323	2.2641	1.42997	1.1754	0.797561
1.0643	0.95913	2.034323	1.02876	1.224995
1.3689	0.8885	1.72173	0.802817	0.659443
1.0546	1.946635	1.092381	1.222246	1.024975
1.3475	0.82948	1.4	0.941374	1.153469
1.5896	1.493245	0.557443	0.833225	1.296

4.4 Summation

This Chapter shows the parameters used for the virtual environments, explain the statistical methods that are used, and presents the data from the experiments. All these data collected in section 4.3 are analyzed and explained in Chapter V. And this data explanation is made with the statistical classification methods mentioned in section 4.2, and has the objective to study the human balance and coordination when the human subject is immersed in virtual environments.

CHAPTER V

RESULTS FROM ANALYSIS

This section shows all the analysis used to examine the human balance and coordination using a head mounted display. These analyses are made with the statistical methods and variables mentioned on Chapter IV. They are divided in contingency tables, t test and correlation analysis.

5.1 Contingency Table (Chi-Square)

5.1.1 Survey Score

The variables considered in this contingency table are in the columns the gender (i.e. male and female) and in the rows contain the presence level (i.e. low, neutral, high). The presence level is divided in three categories, which divides the score from one to fourteen for the low level, from 15 to 28 for the medium level and from 29 to 42 for the high level of presence. Table 5.1 shows the quantity of the subjects who correspond to the specific column and row. The matrixes used are shown from left to right with the observed values, the expected values and at last the test values. This analysis is made with the formulas mentioned in section 4.2.1, and the p value is shown under the test matrix. Also, in Table 5.2 a parallel analysis is shown, where the analysis considers only two levels (i.e. high, and not high presence) instead of three, and it maintains the two genders that were used before. This approach was taken to consider if there is a significance difference in any of both scenarios.

Table 5.1 Survey Score Contingency Table for Presence (three levels)

Observed

	Female	Male
High Presence	26	20
Neutral Presence	3	7
Low Presence	1	3

Expected

	Female	Male
High Presence	23	23
Neutral Presence	5	5
Low Presence	2	2

Test

	Female	Male
High Presence	0.391304	0.391304
Neutral Presence	0.8	0.8
Low Presence	0.5	0.5
		P Value
		0.184279

Table 5.2 Survey Score Contingency Table for Presence (two levels)

Observed

	Female	Male
Not High	4	10
High	26	20

Expected

	Female	Male
Not High	7	7
High	23	23

Test

	Female	Male
Not High	1.285714	1.285714
High	0.391304	0.391304
		P Value
		0.06704

5.1.2 Ball Drop

In the contingency table for ball drop, it is possible to determine if the drop of the ball is dependent to one of the genders (i.e. male and female). This is based on how many times the subjects drop the ball on the complete track. There are three levels depending on how many times the ball is dropped on the route, which are high, medium and low. These levels are based on the maximum times that a subject had dropped the ball (i.e. 23 times), splitting the time from 0 to 6 for low dropping, from 7 to 14 for medium dropping and from 15 and more for high dropping. Table 5.3 shows the observed matrix, the expected matrix and the test matrix to identify the p value for this analysis.

Table 5.3 Drop Ball Contingency Table

Observed

	Female	Male
Low Drops	12	22
Neutral Drops	14	5
High Drops	4	3

Expected

	Female	Male
Low Drops	17	17
Neutral Drops	9.5	9.5
High Drops	3.5	3.5

Test

	Female	Male
Low Drops	1.470588	1.470588
Neutral Drops	2.131579	2.131579
High Drops	0.071429	0.071429
		P Value
		0.025385

The analysis shown above was made with the complete path, other scenario which were analyzed were focused in the three events (i.e. the explosion, the meteors and the bird flock). In the contingency table, which is Table 5.4, there are three levels (i.e. no dropping, low dropping and high dropping), where no dropping is when the subject did not drop the ball in any event, and the low and high dropping are separated when the subject drops 1 time for low dropping and 2 or more times the ball for high dropping. Table 5.4 shows this analysis with the corresponding matrixes.

Table 5.4 Drop Ball Contingency Table for specific events

Observed

	Female	Male
No Drop	6	18
Low Drop	13	4
High Drop	11	8

Expected

	Female	Male
No Drop	12	12
Low Drop	8.5	8.5
High Drop	9.5	9.5

Test

	Female	Male
No Drop	3	3
Low Drop	2.382353	2.382353
High Drop	0.236842	0.236842
		P Value
		0.003628

5.2 T-Test

5.2.1 Track Time

This test is made to compare the total track time of the male and female subjects. The mean value is compared considering the values from the experiment subjects in table 4.4. For this analysis, the variances are assumed as equal, and the P-Value is of 0.958, which means that there is not a significance difference between male and female subjects. Figure 5.1 shows the boxplot for this analysis.

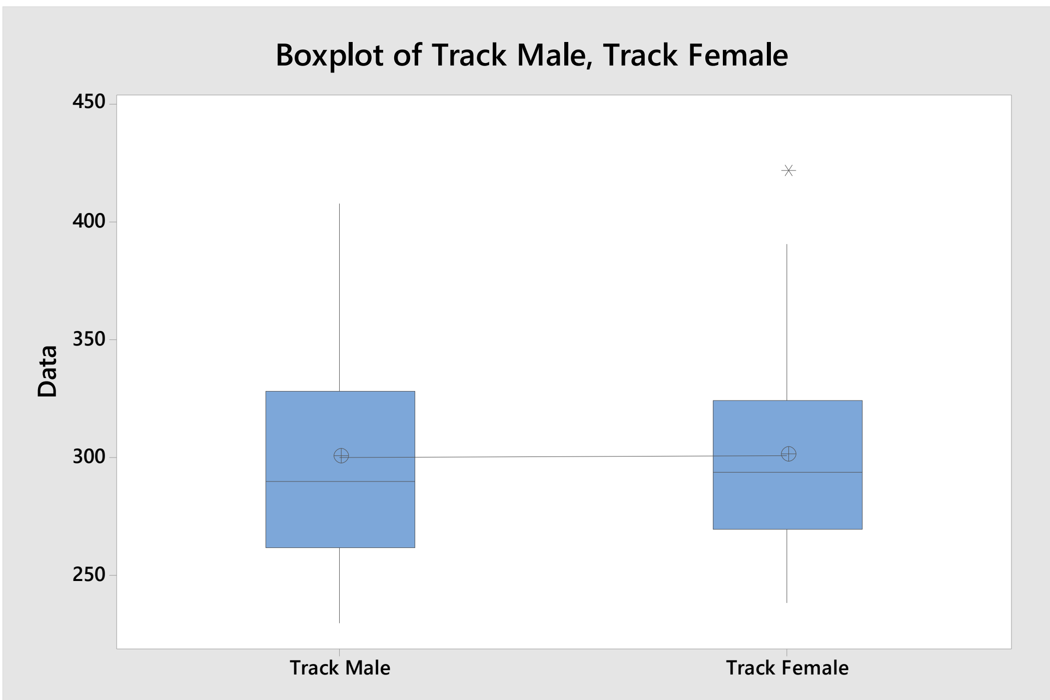


Figure 5.1 Boxplot for Track Time

5.2.2 Time to Reset the Ball

This analysis is made to compare the average time of the subjects to reset the ball, and the data from the male and female subjects from table 4.5 is gathered to be analyzed with the t test method for independent variables. Figure 5.2 shows the boxplot from this t test analysis, where the variances were considered different and with a P-Value of 0.325.

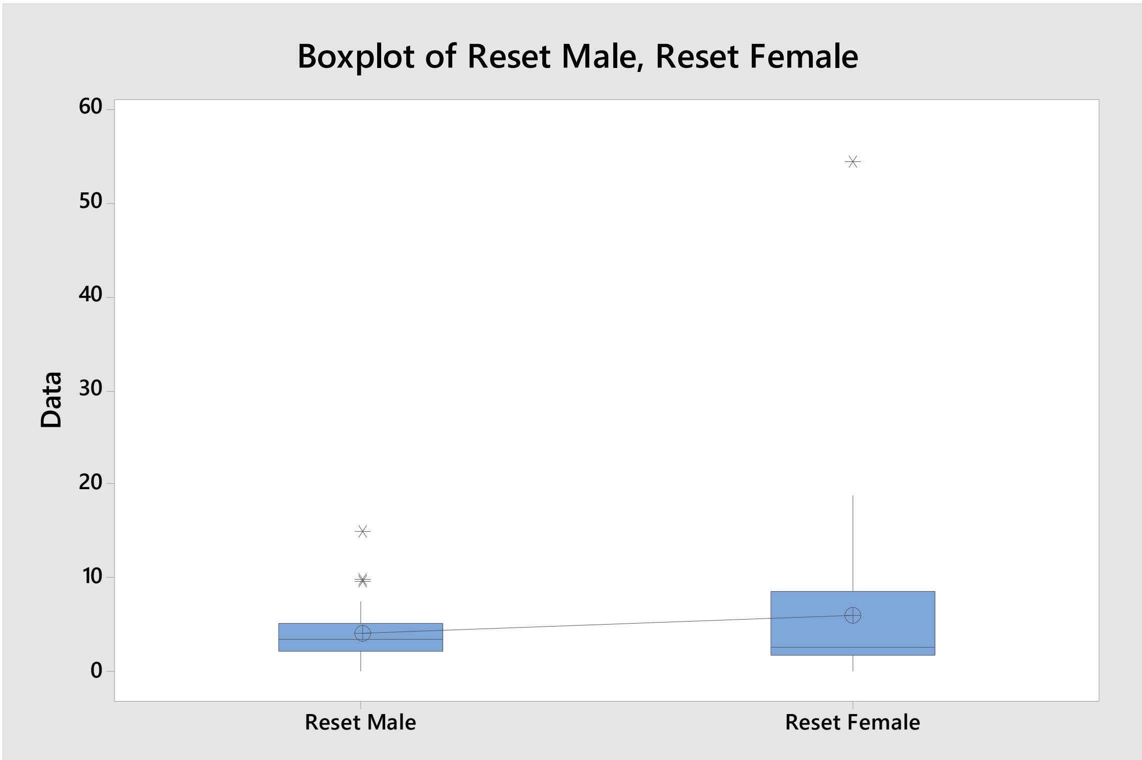


Figure 5.2 Boxplot for the Time to Reset the Ball

5.2.3 Balancing Time

This analysis is made considering the total track time of the subjects minus the total time to reset the ball, which means that the analysis considers only the time that the ball was balanced. The data used for this analysis is gathered in table 4.6. Figure 5.3 shows the boxplot for the balancing time. In this t test the variance is assume equal for both variables and the P-Value for balancing the ball is 0.994.

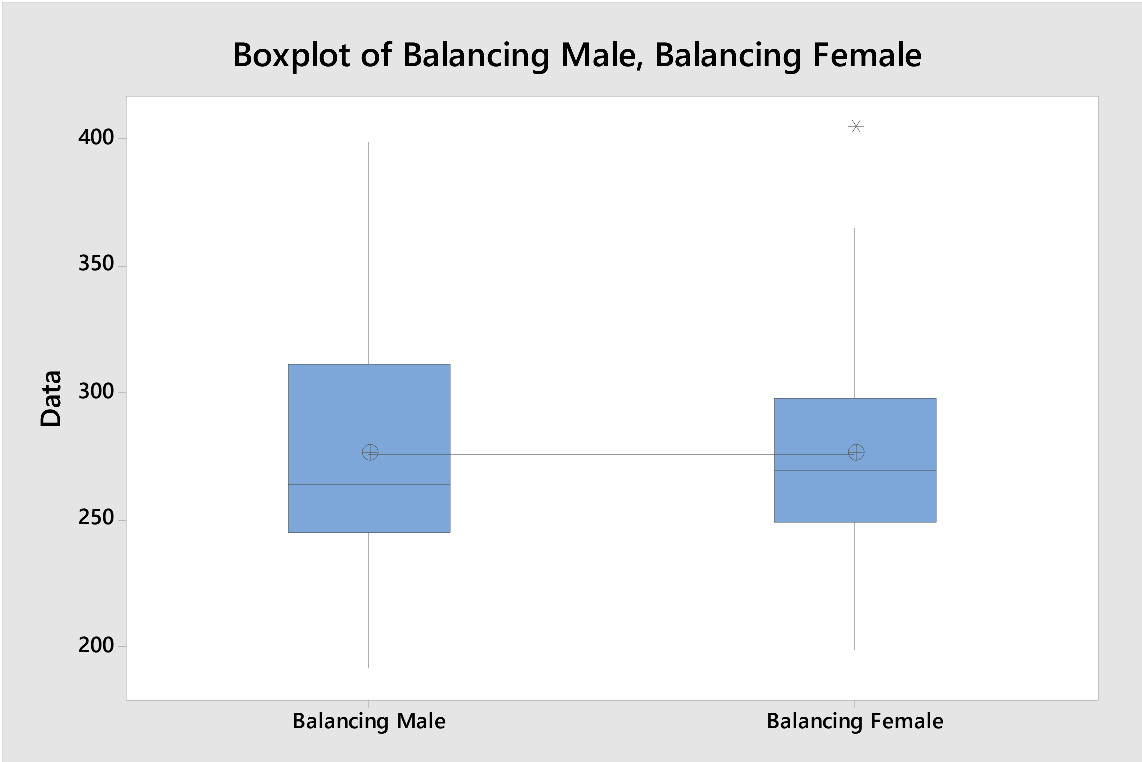


Figure 5.3 Boxplot for the Balancing Effective Time

5.2.4 Ball Drop

The times that the ball has been dropped in the experiment is one of the most important variables in this study. The data used for this analysis is shown in table 4.7 (a) and (b) for the complete track and when the stimuli events happen, respectively. The mean value of the male and female subjects is compared with the t test, and in figure 5.4 and 5.5 the boxplots from this analysis are shown. On both t tests the variance is assumed as the same for both variables, the P-Value for dropping the ball in the complete path is of 0.172 and the P-Value for dropping the ball in the events is of 0.013.

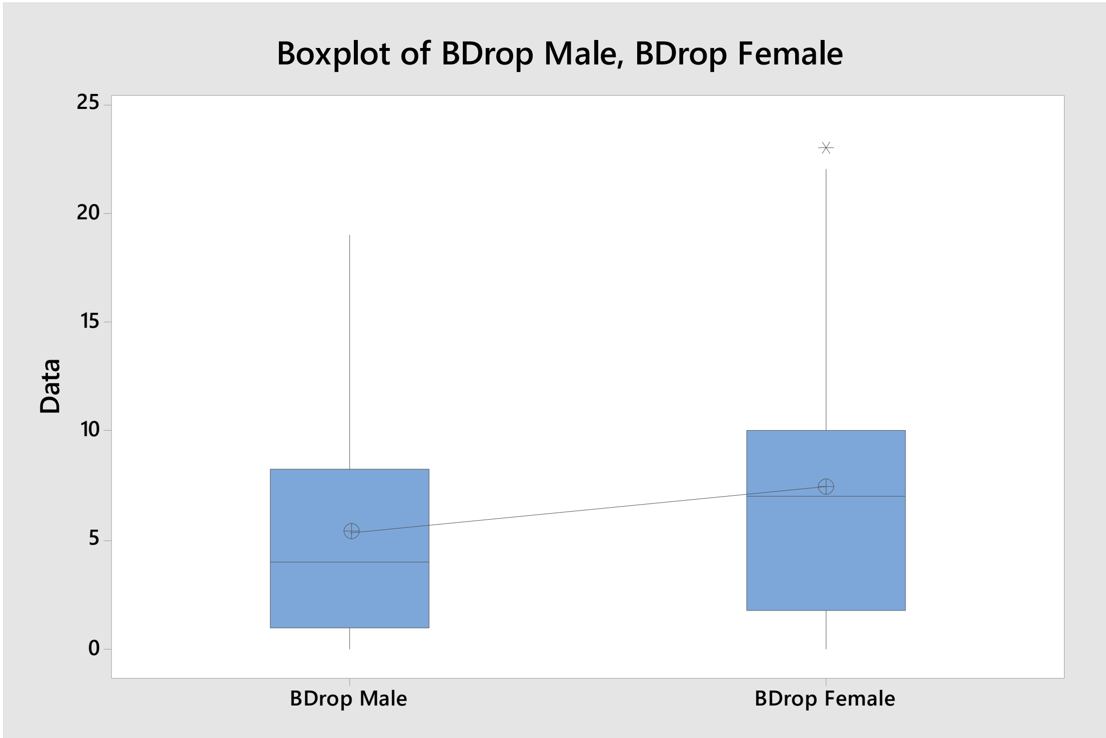


Figure 5.4 Boxplot for how many Times the Ball was Dropped on the complete Track

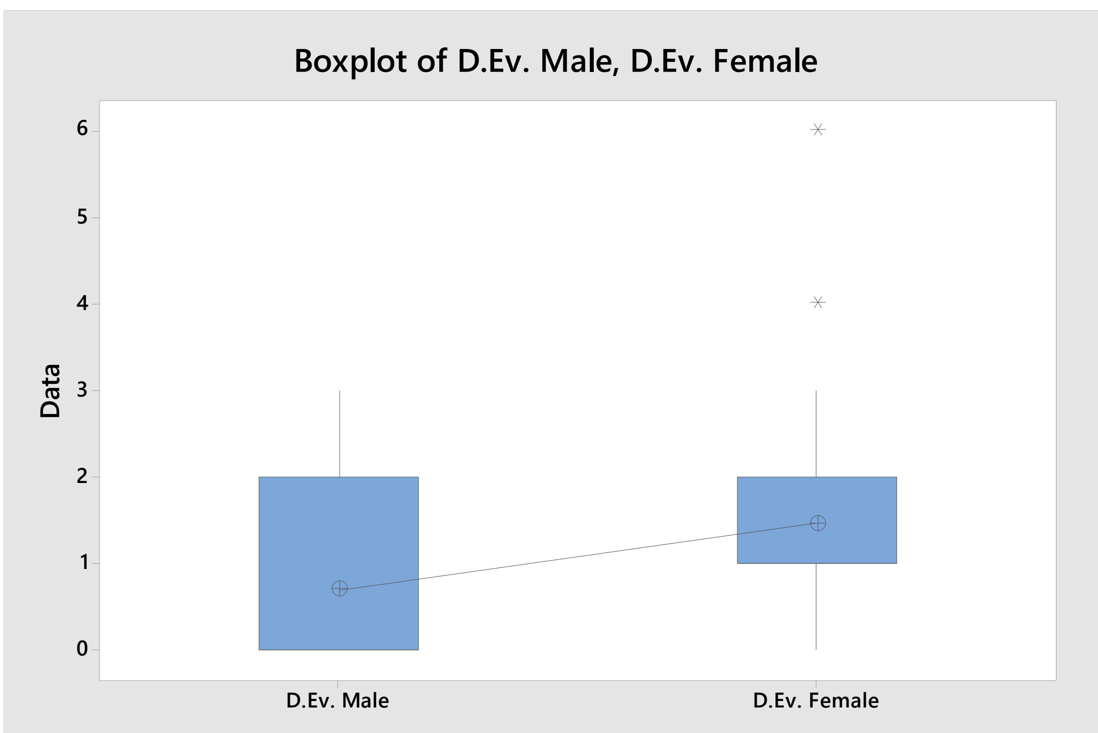


Figure 5.5 Boxplot for Dropping the Ball during the Events

5.2.5 Ball Speed

For the ball speed there are two scenarios, where the average speed value is shown during the experiment and the delta (highest difference between speed values) speed of the ball on this same period. The data used for the average speed comes from table 4.8 (a), and for this analysis the variance is assumed as equal and has a P-Value of 0.125. And, in Figure 5.6 the boxplot for the ball average speed is shown.

On the other hand, the figure 5.7 shows the boxplot of the data for the delta speed of the ball, and this data was taken from table 4.8 (b). For the delta speed analysis, it is assumed that the variables have different variances and the test has a P-Value of 0.601.

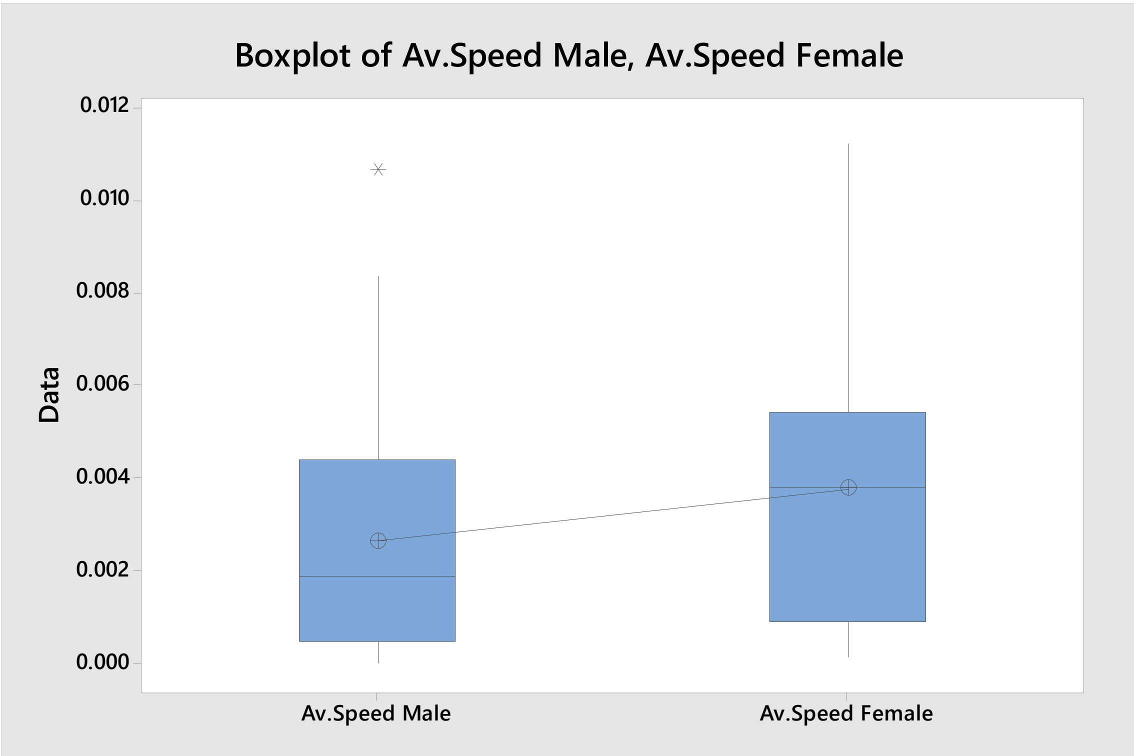


Figure 5.6 Boxplot for the Average Ball Speed

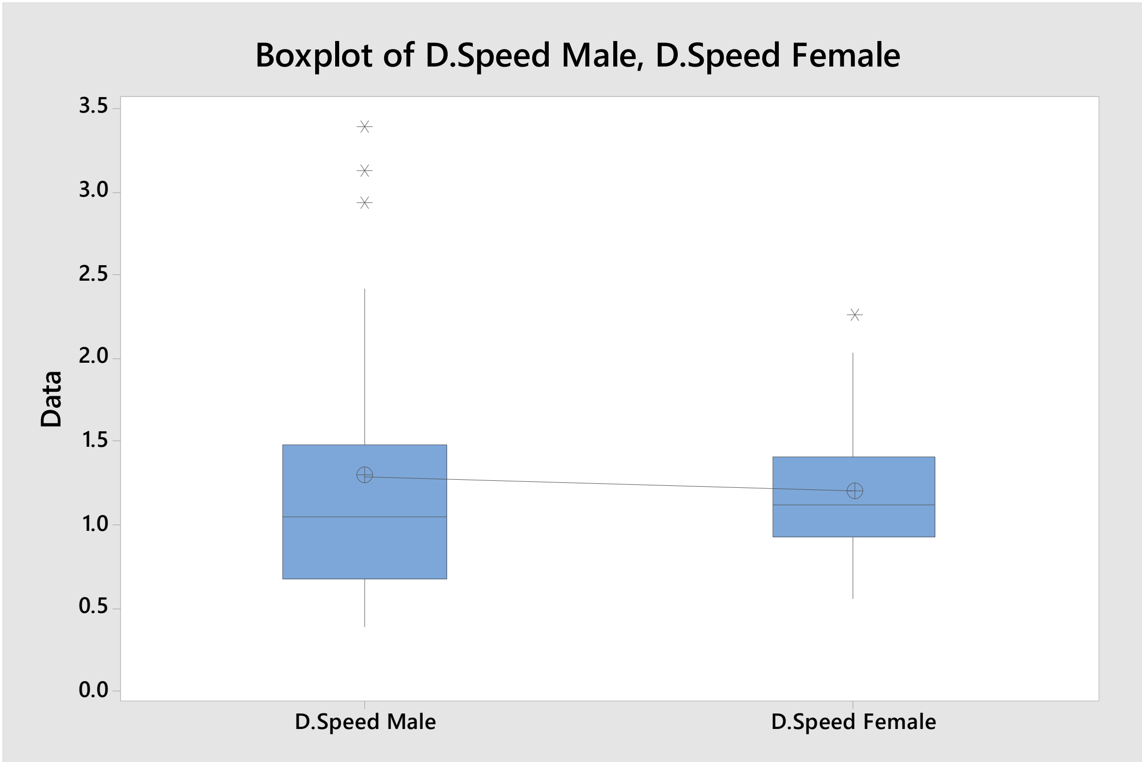


Figure 5.7 Boxplot for the Delta Ball Speed

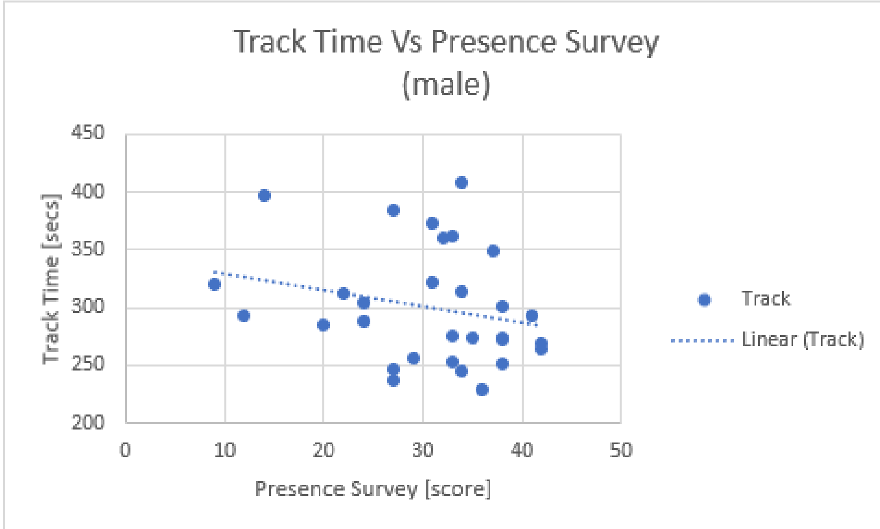
5.3 Correlation

5.3.1 Presence Survey Score vs Track Time

The correlation between the survey score and the track time for the male and female subjects are shown in figure 5.8. Also below is shown the correlation coefficient for each of these analyses.

Male Correlation Coefficient: -0.246

Female Correlation Coefficient: -0.045



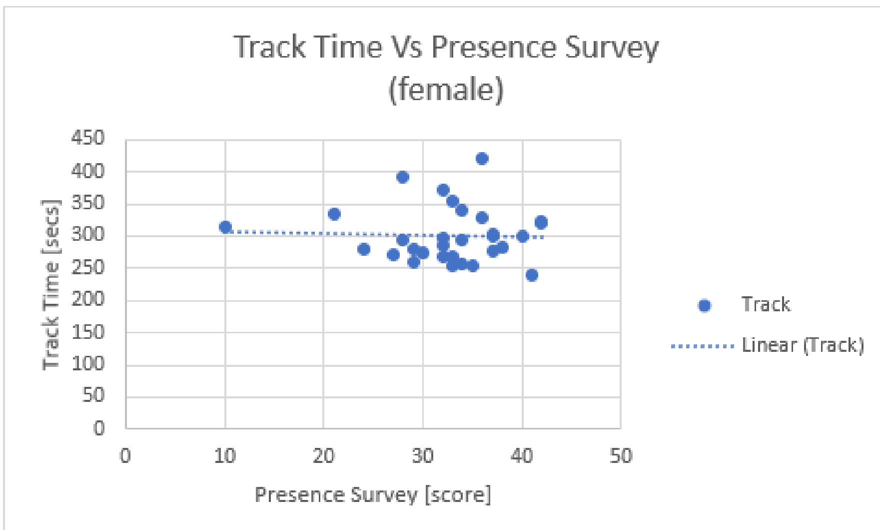


Figure 5.8 Correlation between Track Time and Presence Survey

5.3.2 Presence Survey Score vs Balancing Time

In figure 5.9 the correlation graph between the balancing time and the presence survey is shown, and the correlation coefficient for male and female subjects are shown below.

Male Correlation Coefficient: -0.216

Female Correlation Coefficient: -0.167

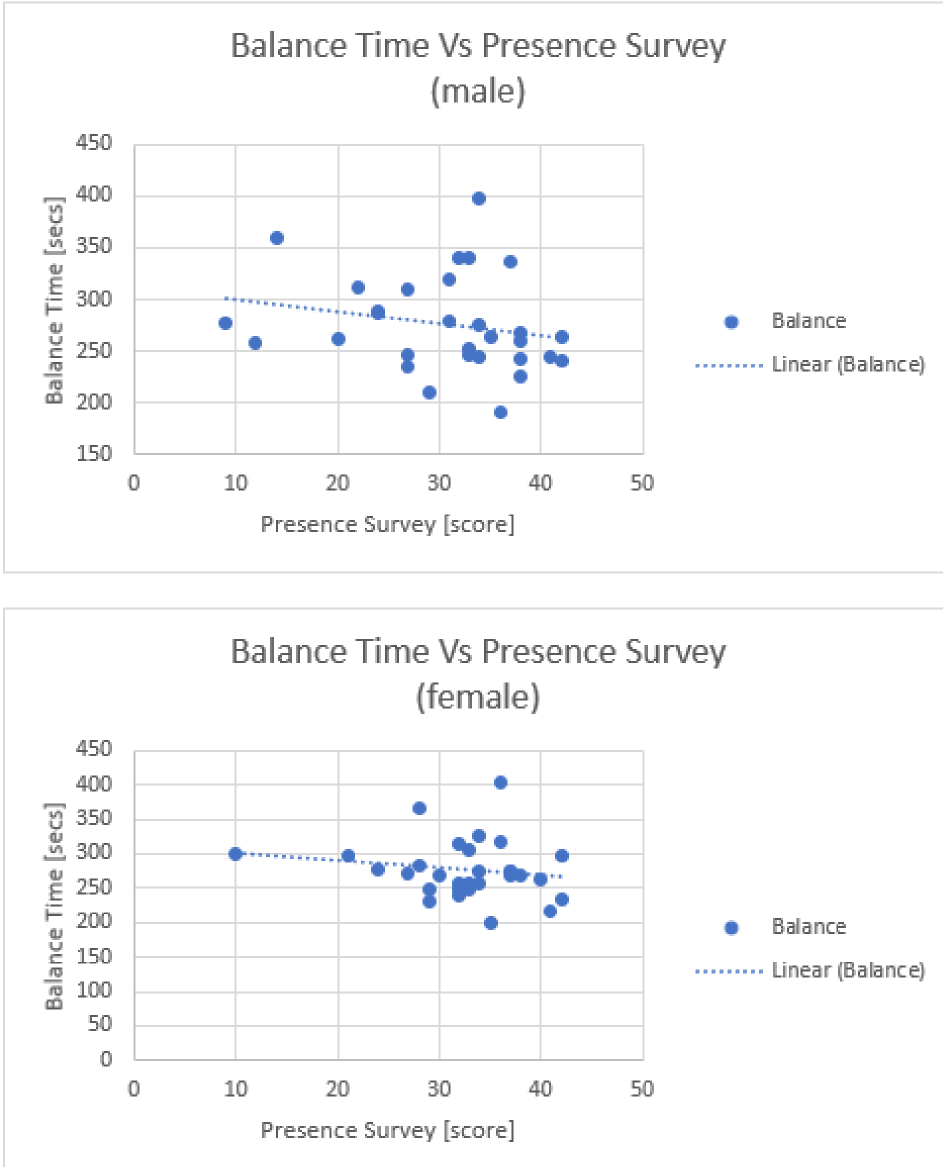


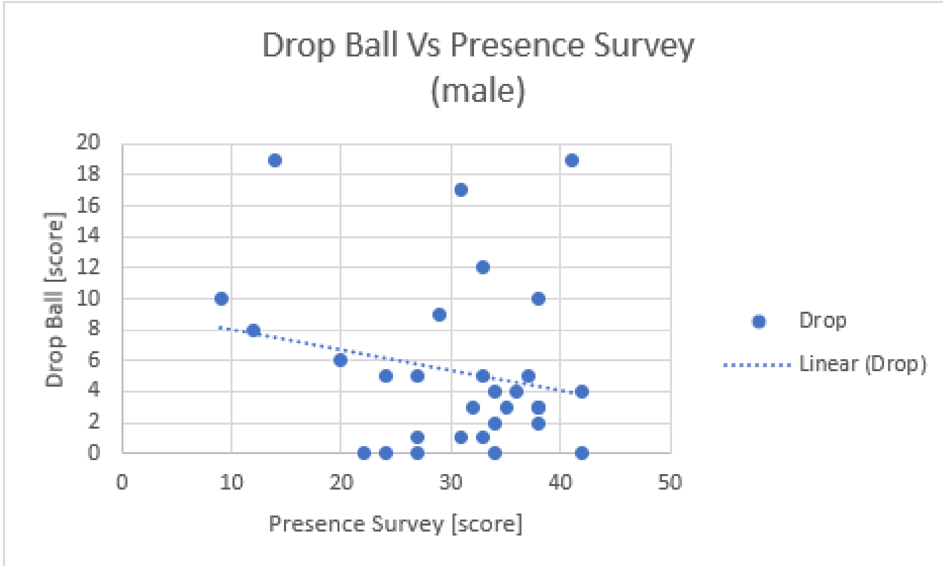
Figure 5.9 Correlation between the Balancing Time and Presence Survey

5.3.3 Presence Survey Score vs Ball Drop

In figure 5.10 the correlation between how many times the ball was dropped and the survey presence score is shown, and the coefficient values for these correlations are shown above their graphs.

Male Correlation Coefficient: -0.204

Female Correlation Coefficient: -0.127



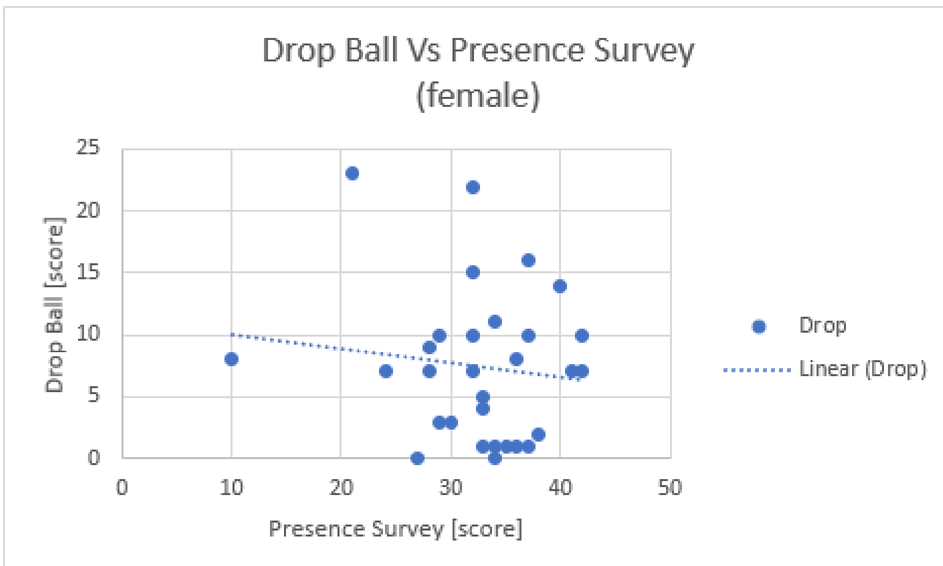


Figure 5.10 Correlation between the Ball Drop and the Presence Survey

5.3.4 Presence Survey Score vs Av. Ball Speed

The average ball speed is analyzed in correlation with the survey score, and the graph for male and female subjects are shown in figure 5.11. And the correlation coefficient value for each of the genders is represented below.

Male Correlation Coefficient: -0.140

Female Correlation Coefficient: -0.093

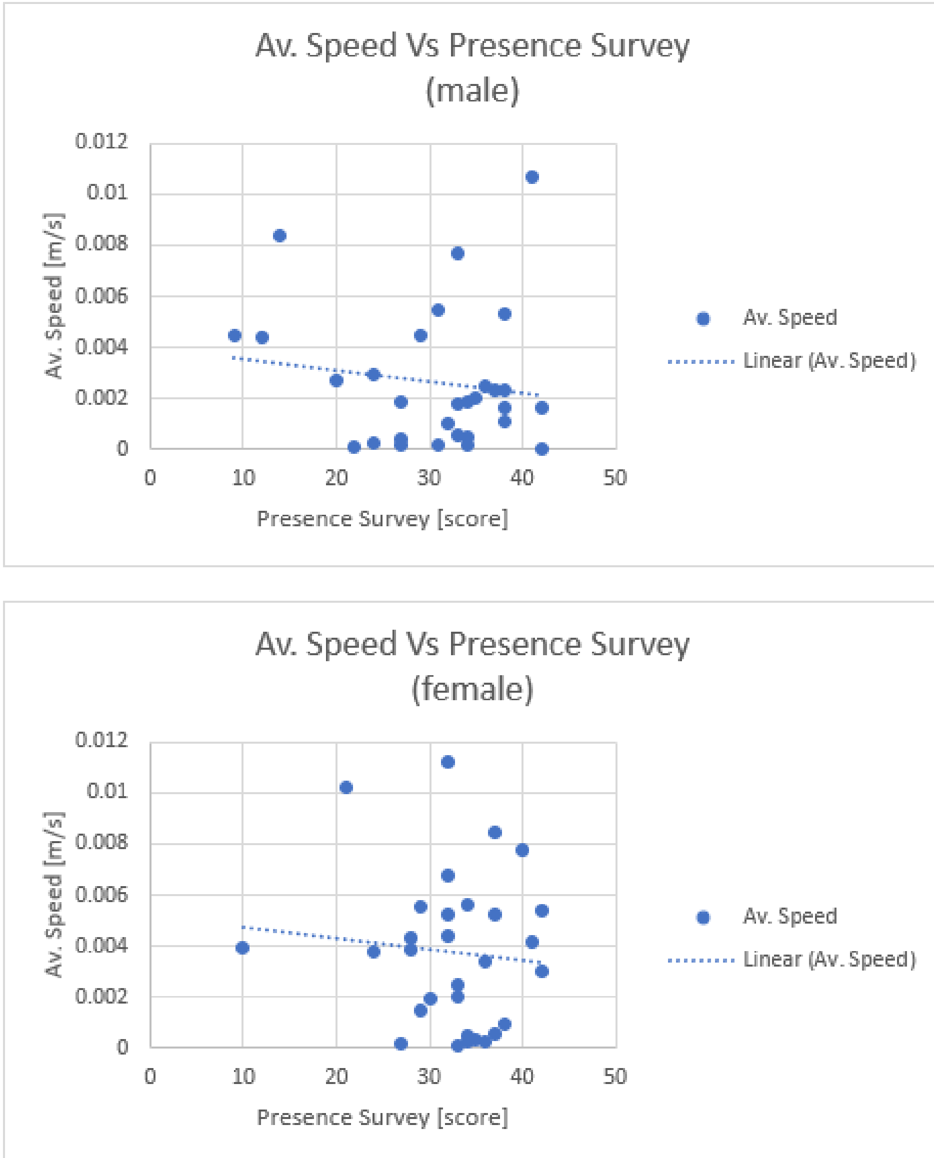


Figure 5.11 Correlation between the Av. Ball Speed and the Presence Survey

5.3.5 Gamer Survey vs Track Time

The correlation between how much the subjects play videogames and the time that it took them to complete the path is represented in figure 5.12, where it is shown the correlation graphs for male and female subjects. And the correlation coefficient for each gender is shown next.

Male Correlation Coefficient: -0.170

Female Correlation Coefficient: -0.246

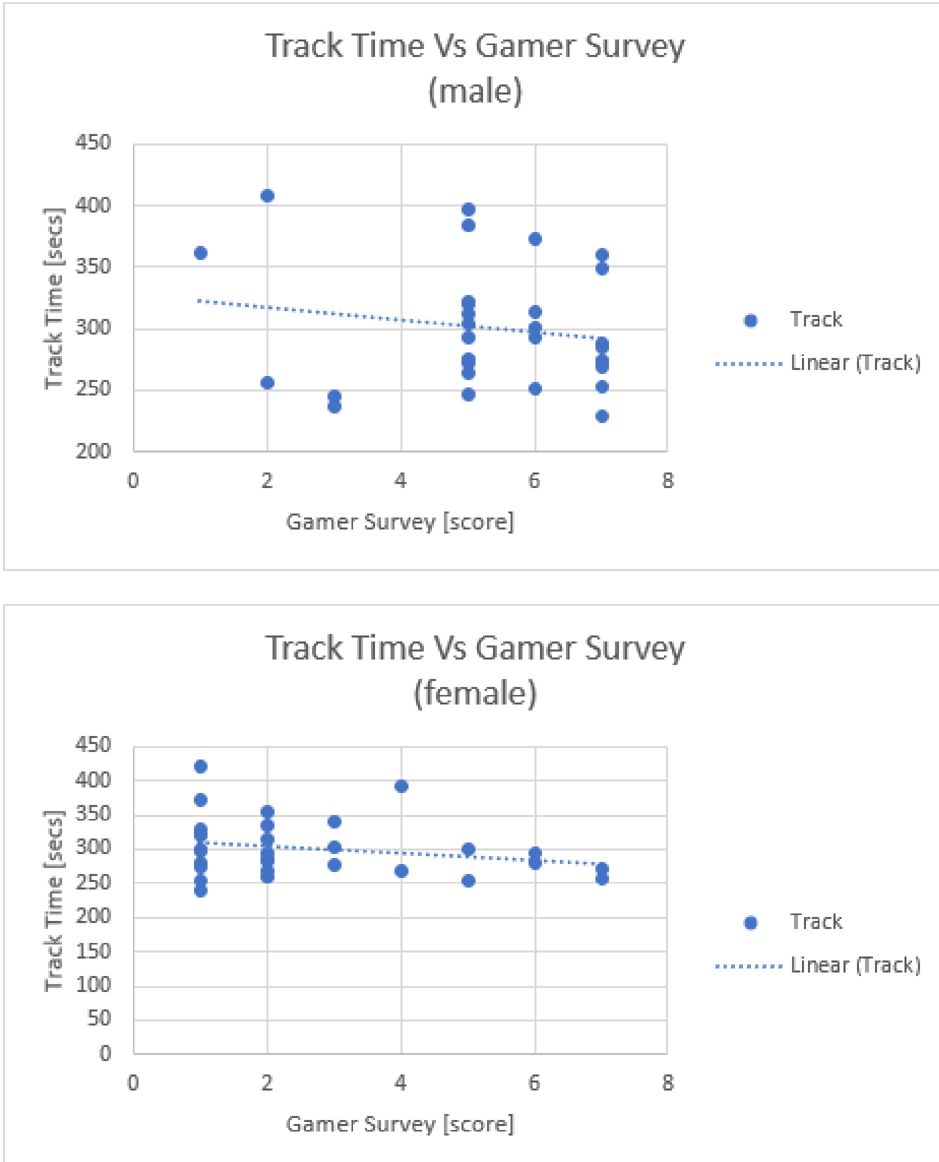


Figure 5.12 Correlation between the Track Time and the Gamer Survey

5.3.6 Gamer Survey vs Balancing Time

In figure 5.13 the correlation graph for the relation between the effective balancing time of the ball is shown, and the survey of the subjects where they respond with the level that they play videogames from one to seven. The coefficients for these analyses are shown below.

Male Correlation Coefficient: -0.208

Female Correlation Coefficient: -0.017

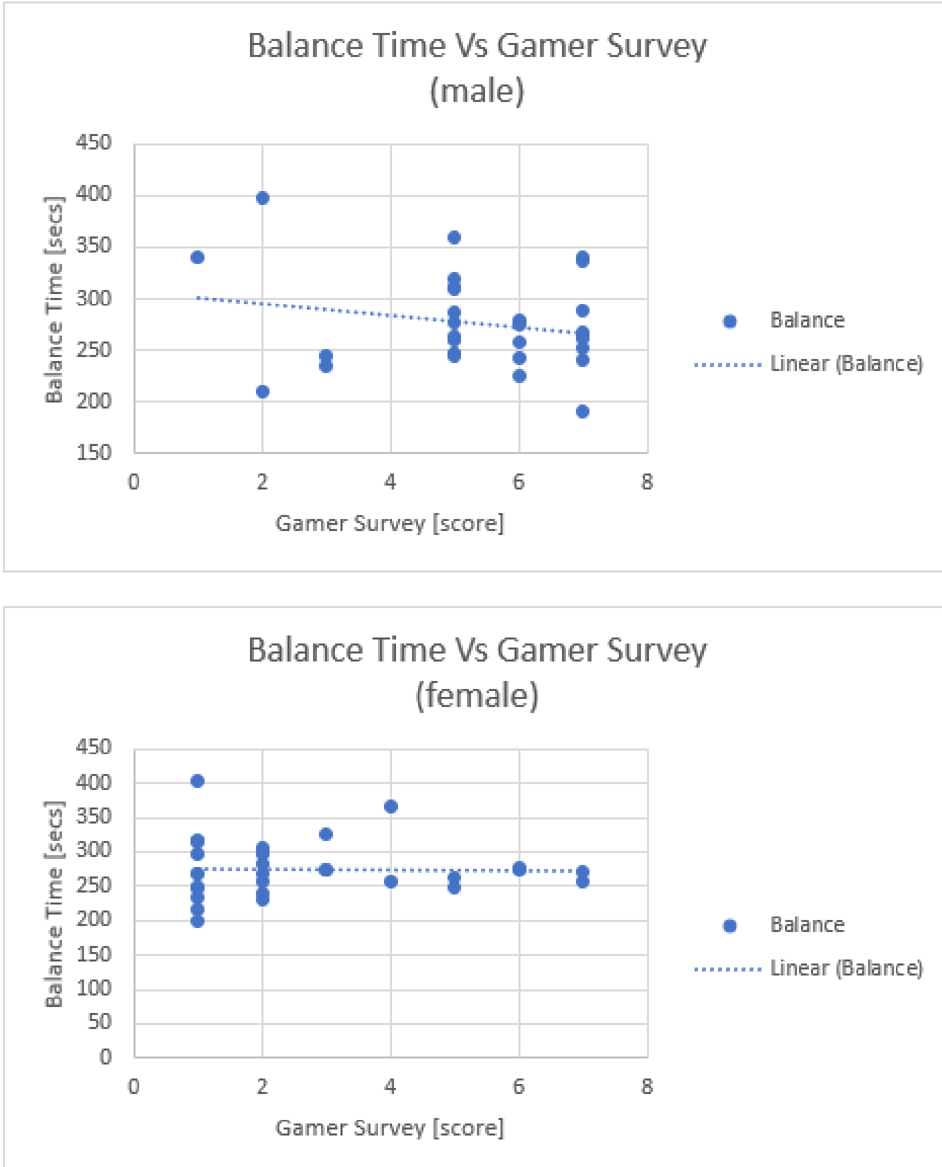


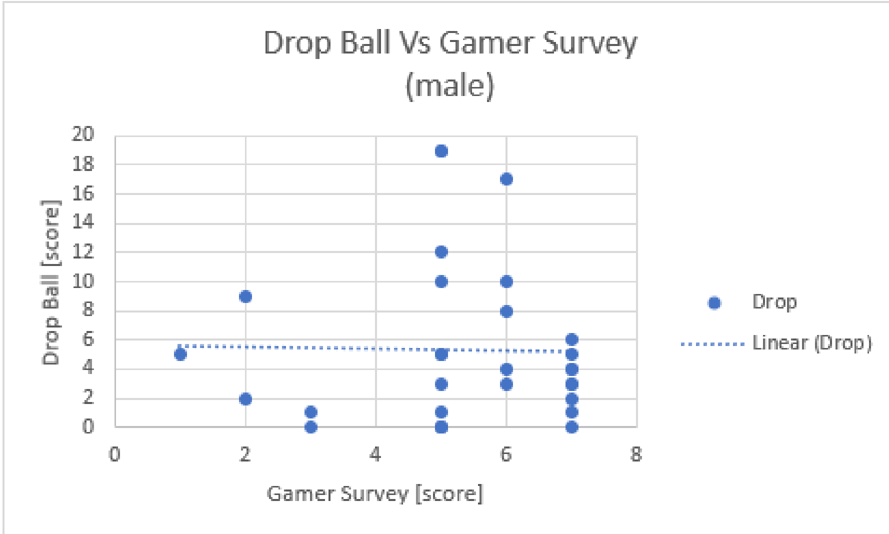
Figure 5.13 Correlation between the Balancing Time and the Gamer Survey

5.3.7 Gamer Survey vs Ball Drop

The correlation between the times that the ball was dropped and the survey about how much the subjects play videogames is shown in figure 5.14. Where the correlation coefficient is shown below with its correspondent gender for the analysis.

Male Correlation Coefficient: -0.020

Female Correlation Coefficient: -0.352



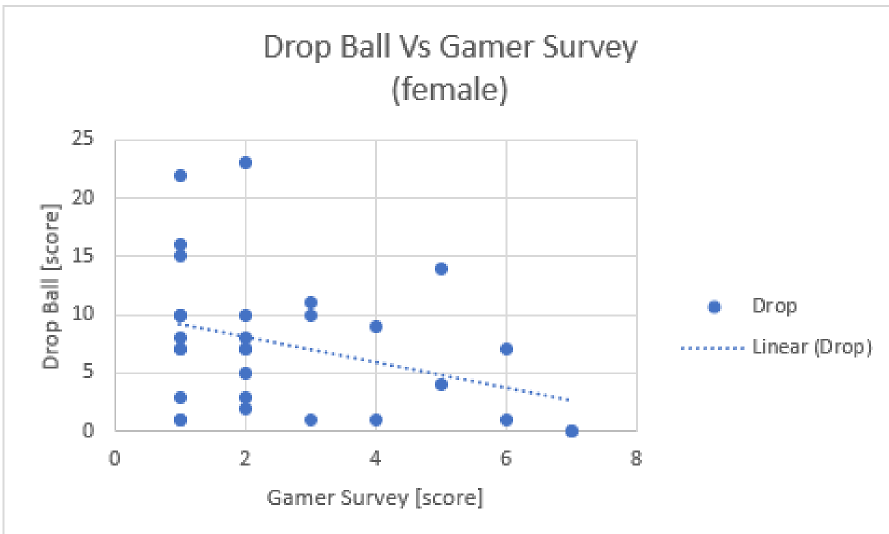


Figure 5.14 Correlation between the Ball Drop and the Gamer Survey

5.3.8 Gamer Survey vs Av. Ball Speed

In figure 5.15 the average ball speed against the answer of the subjects of how much they play videogames is compared, and the correlation is displayed above the graph. This analysis is made with both genders (i.e. male and female), and the corresponding correlation coefficient is represented as:

Male Correlation Coefficient: 0.004

Female Correlation Coefficient: -0.333

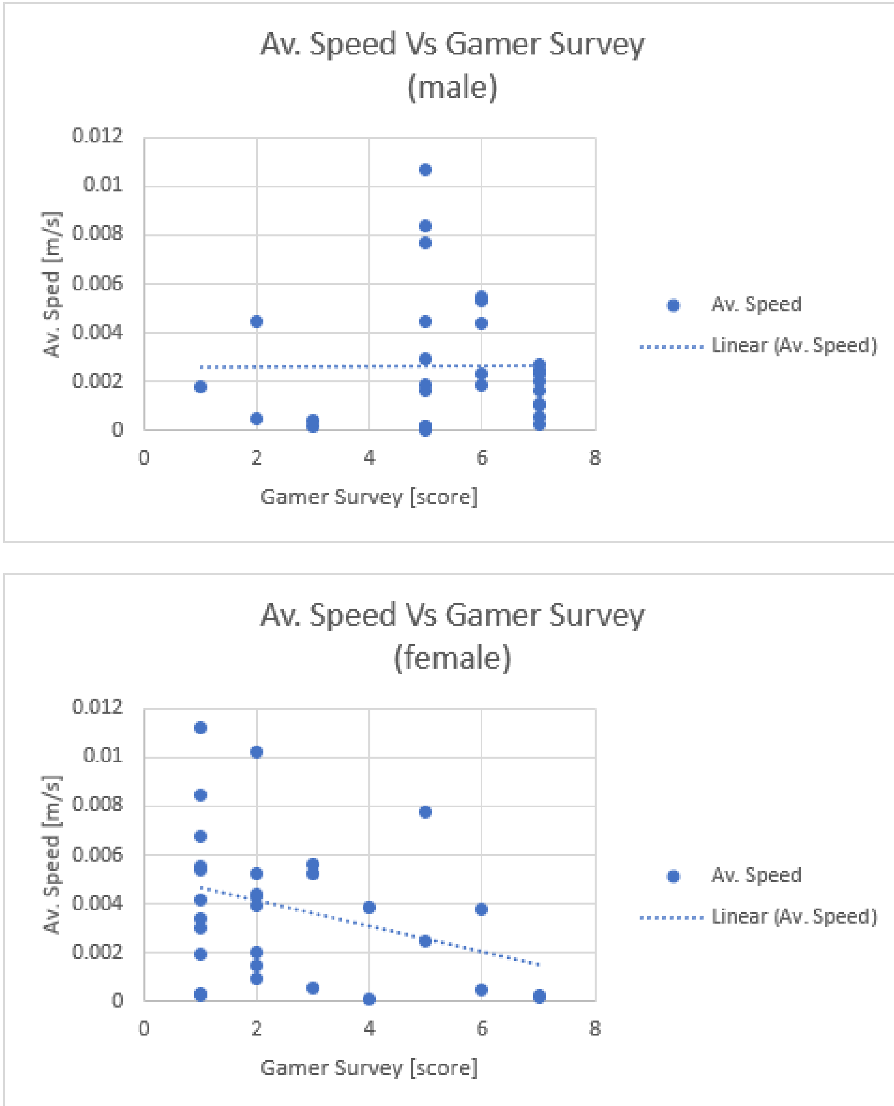


Figure 5.15 Correlation between the Av. Ball Speed and the Gamer Survey

5.3.9 Difficult to Balance Survey vs Track Time

The correlation between the time that it takes to complete the path is compared in figure 5.16 against the feeling of balancing the ball (how hard was it) in the virtual environment. The correlation coefficient for the male and female subjects is:

Male Correlation Coefficient: -0.019

Female Correlation Coefficient: 0.317

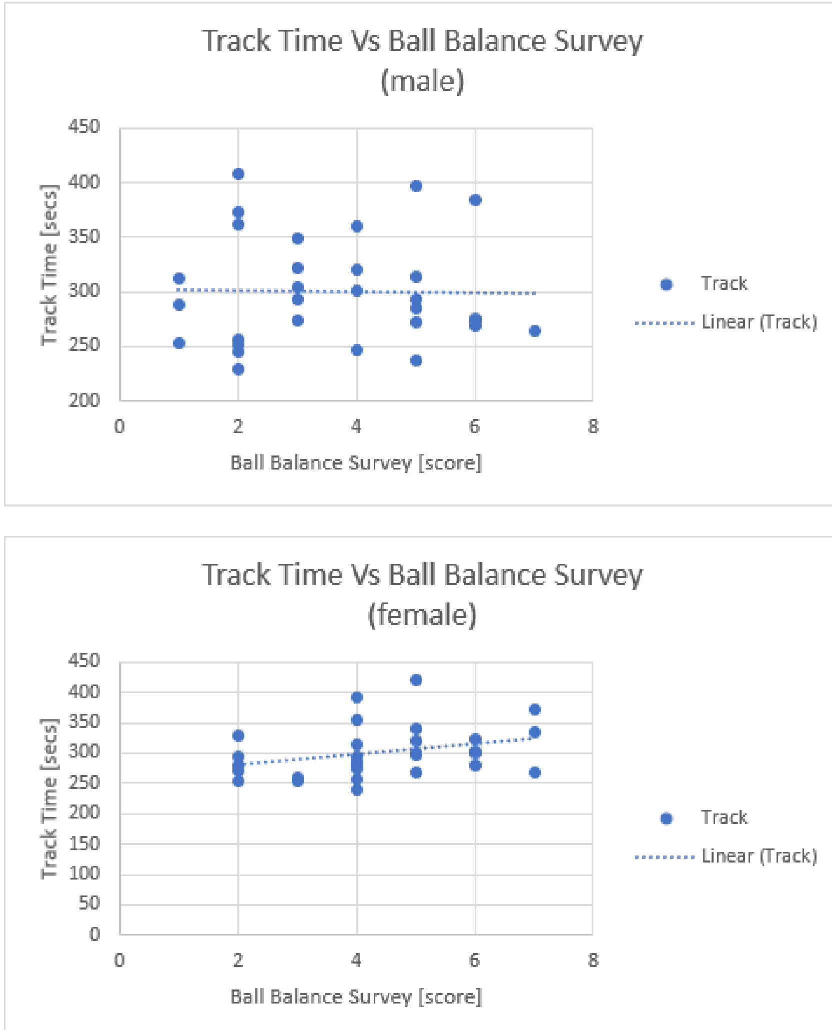


Figure 5.16 Correlation between the Track Time and the Difficult to Balance the Ball Survey

5.3.10 Difficult to Balance Survey vs Balancing Time

In figure 5.17 the correlation between the total effective time that the ball was balanced during the experiment against the subject sensation of difficulty to balance the ball is shown. And, the correlation coefficient for male and female subjects for the comparison between the effective balancing time and the survey for the difficulty to balance the ball is:

Male Correlation Coefficient: -0.109

Female Correlation Coefficient: 0.127

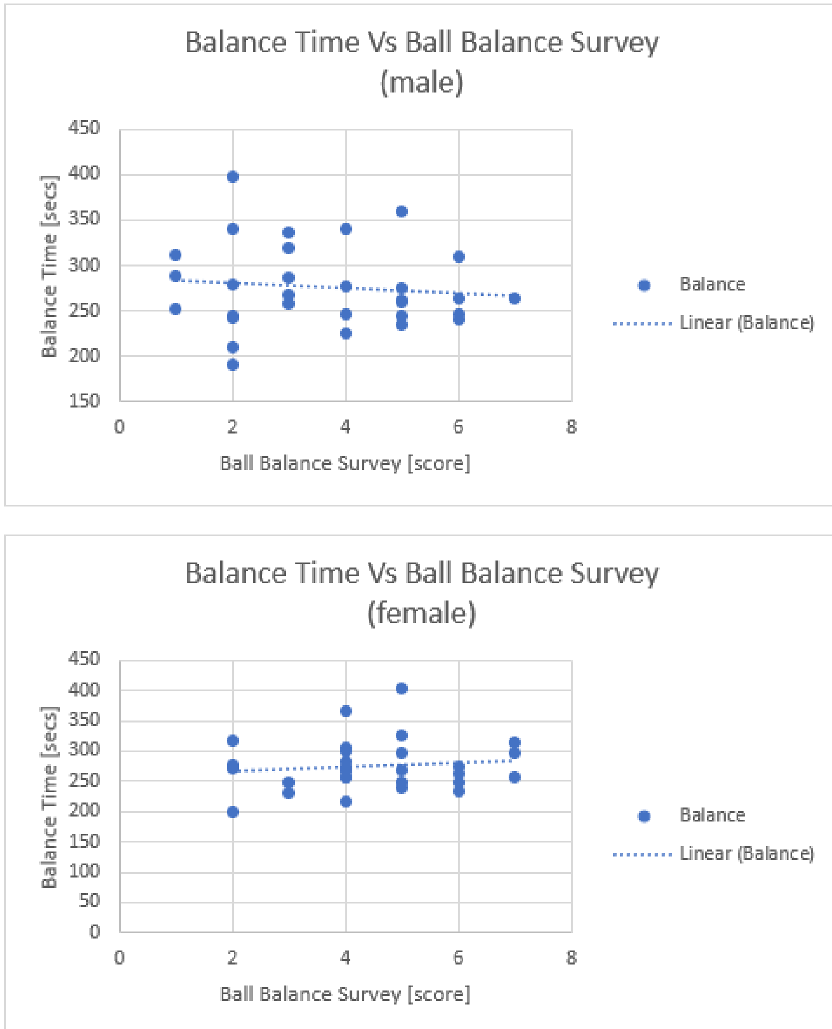


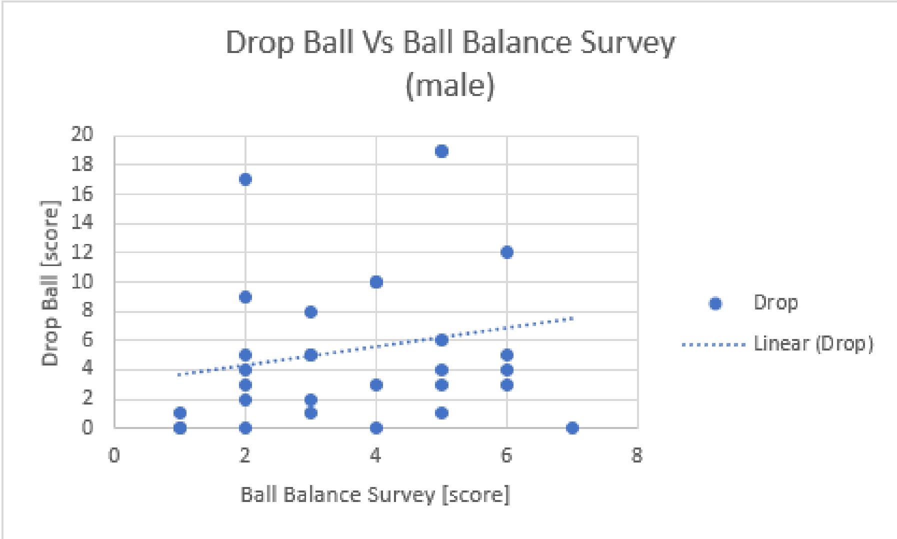
Figure 5.17 Correlation between the Balancing Time and the Difficult to Balance the Ball Survey

5.3.11 Difficult to Balance Survey vs Ball Drop

The correlation between how many times during while immersed in the virtual environment and the difficulty sensation to balance the ball of the subject is shown in figure 5.18, while the correlation coefficient for each gender is shown below.

Male Correlation Coefficient: 0.200

Female Correlation Coefficient: 0.623



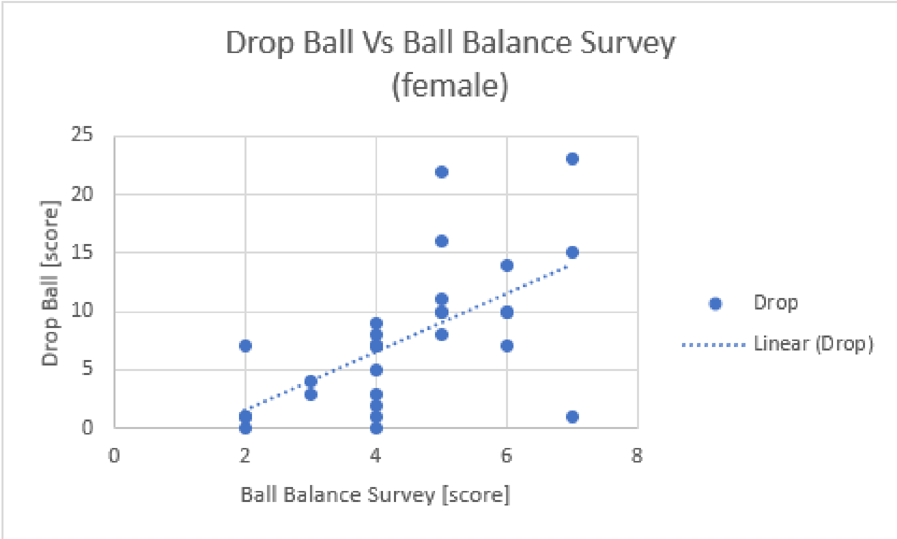


Figure 5.18 Correlation between the Ball Drop and the Difficult to Balance the Ball Survey

5.3.12 Difficult to Balance Survey vs Av. Ball Speed

The average ball speed on the plate is compared to the subjects' sensation of difficulty balancing the ball during the experiment, and it is represented in figure 5.19. Also, the correlation coefficient is:

Male Correlation Coefficient: 0.245

Female Correlation Coefficient: 0.588

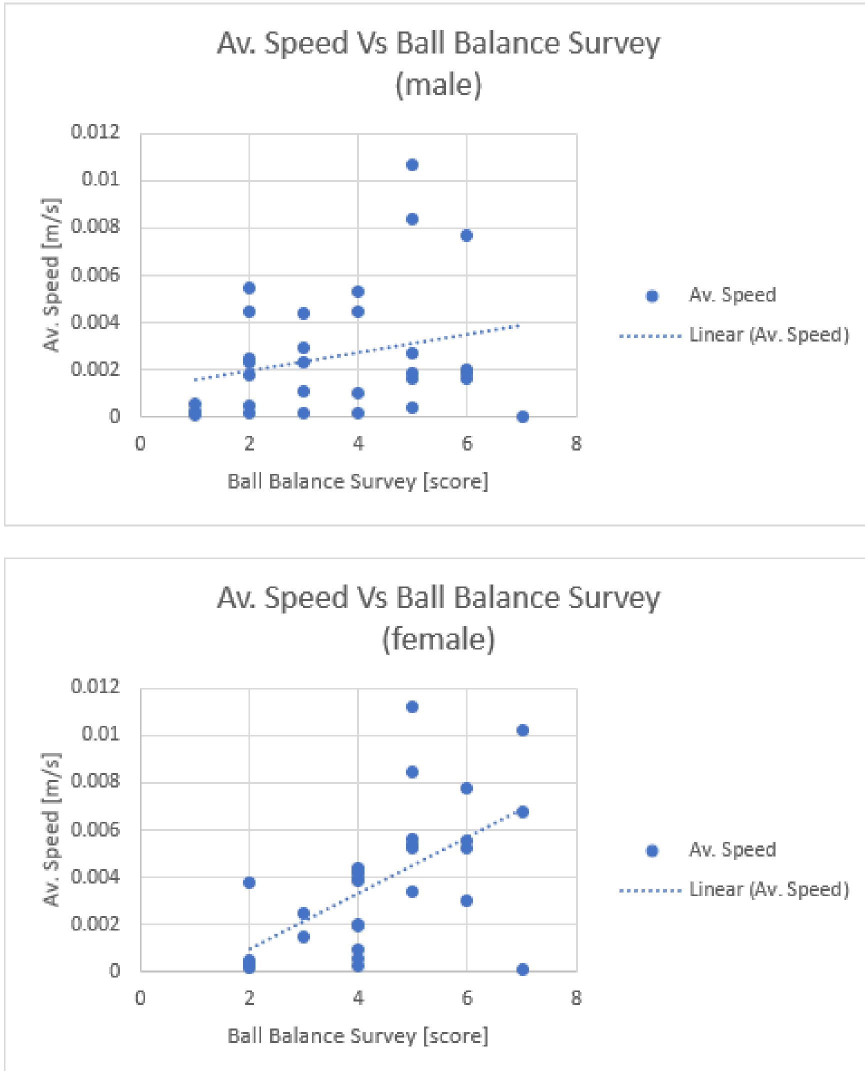


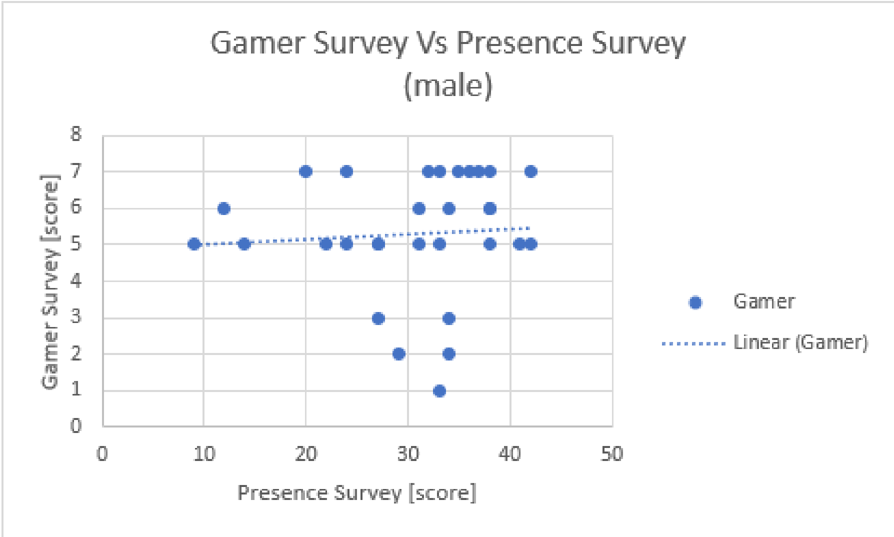
Figure 5.19 Correlation between the Av. Ball Speed and the Difficult to Balance the Ball Survey

5.3.13 Presence Survey Score vs Gamer Survey

The correlation between the subjects' presence against their experience in videogames is shown in figure 5.20. And the coefficient for this correlation is shown below.

Male Correlation Coefficient: 0.071

Female Correlation Coefficient: -0.153



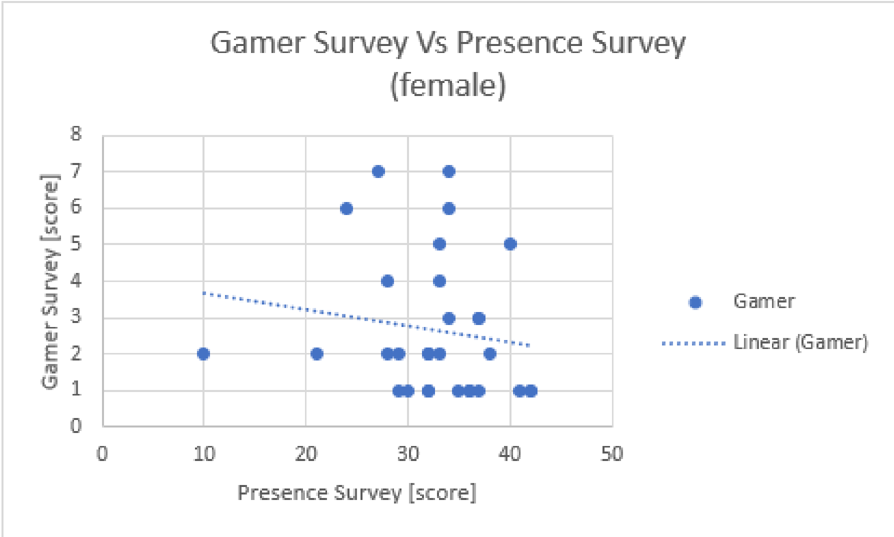


Figure 5.20 Correlation between the Gamer Survey and the Presence Survey

5.3.14 Presence Survey Score vs Difficult to Balance Survey

The subjects' feeling of presence in a virtual environment is compared with their sensation of difficulty at the moment to balance the ball in this virtual environment, and the correlation for this relation is shown in the graphs from figure 5.21. Also, the correlation coefficient of this comparison is:

Male Correlation Coefficient: 0.140

Female Correlation Coefficient: 0.121

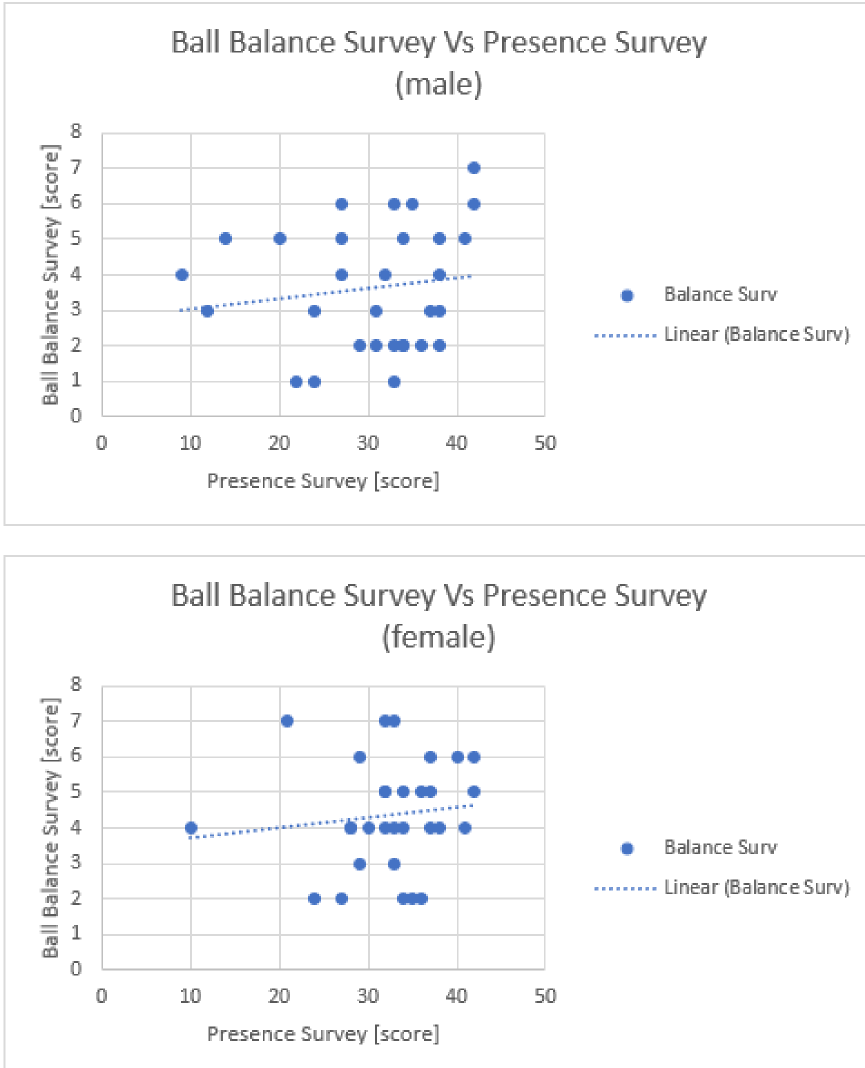


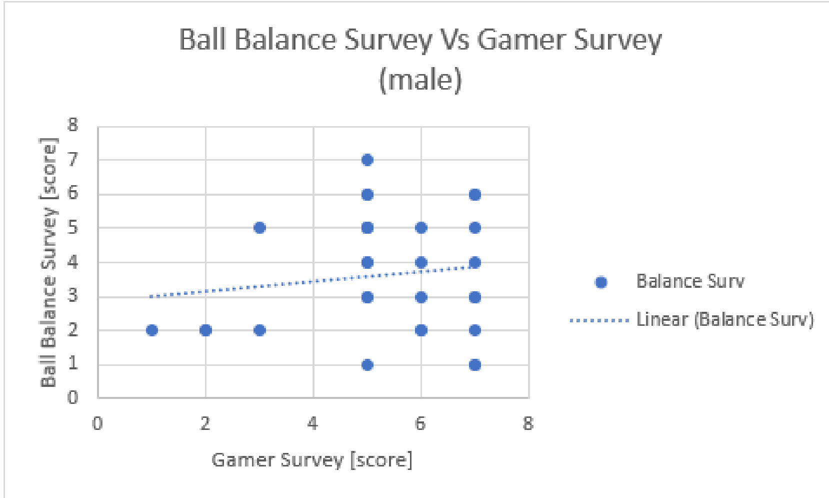
Figure 5.21 Correlation between the Difficult to Balance the Ball Survey and the Presence Survey

5.3.15 Gamer Survey vs Difficult to Balance Survey

In figure 5.22 the correlation between the sensation of difficulty to balance the ball from the subjects who participate in the experiment, and their experience playing videogames is represented. And, the corresponding correlation coefficient for these analyses is:

Male Correlation Coefficient: 0.135

Female Correlation Coefficient: -0.332



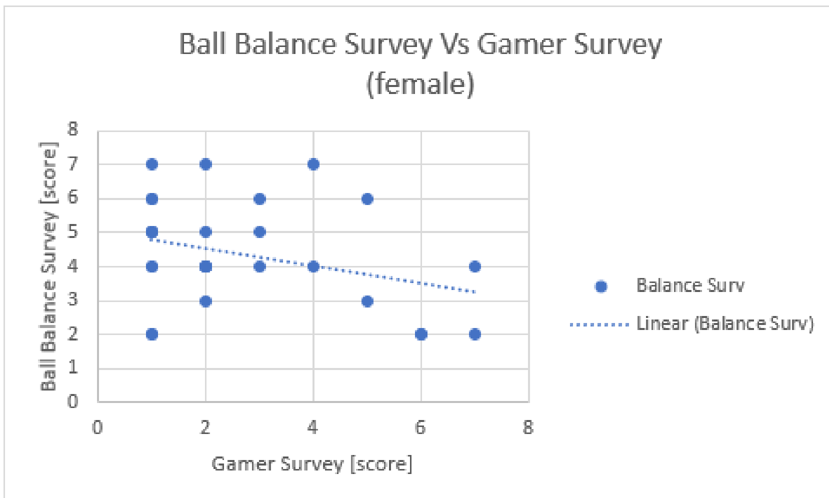


Figure 5.22 Correlation between the Difficult to Balance the Ball Survey and the Gamer Survey

5.4 Phase Plane

For the phase plane, three plots for each subject (one for each event) is generated. For that reason, the phase plane compilation is shown in Appendix D, where the 180 plots can be shown. Below in figure 5.23 are shown the phase planes from the gathered phase planes of male and female subjects.

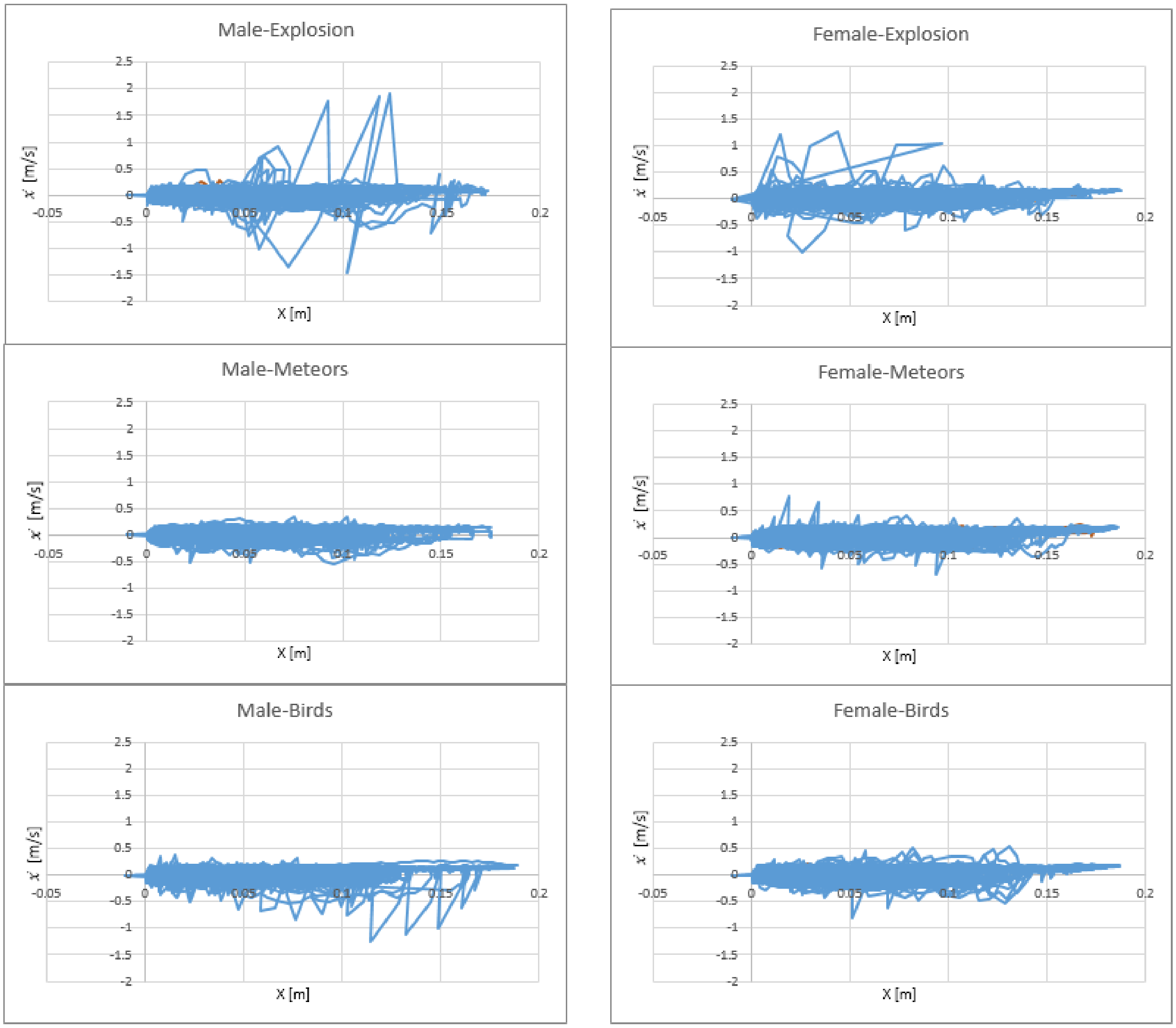


Figure 5.23 Phase Plane of Male and Female Subjects

CHAPTER VI

CONCLUSIONS

There were used four different analysis methods in this research, for that reason the conclusions are separated by the different methods, explaining the result from each analysis, with the different variables that were studied. After the individual explanation from the contingency tables, the t test, correlation and the phase planes, a general conclusion is made from the different analysis. The research thesis is analyzed to affirm or deny that there is a difference by comparison between male and female subjects in virtual environments. As one last point, other analysis possibilities are explained and possible future research that can be done with the existent data.

6.1 Contingency Table (Chi-Square)

Table 6.1 summarize the results from the different analysis made with the contingency tables. It shows the P-Value results and the observations from each case. The studied variables were the presence in two and three levels, and the performance dropping the ball in the complete path and during the stimuli events. The details from these four cases are explained with more details after the table.

Table 6.1 Summary of Contingency Table

	P-Value	Observations
Presence 3-levels	0.1842	No dependency or difference
Presence 2-levels	**0.067**	Female subjects close to have a higher presence
Drop Ball (complete path)	**0.0253**	Male subjects drop the ball less, having a better performance
Drop Ball (during events)	**0.0036**	Male subjects drop the ball less, having a better performance

There is a total of four contingency tables, two analyzing the presence and two analyzing how many times the ball is dropped. Presence is analyzed in two and three levels as discussed in chapter V. There is a higher statistical difference in the two level analysis. This two level analysis is between high and not high presence, where female subjects have a higher presence with an accuracy of 90%. This research looks for a 95% precision, for that reason this contingency table analysis is not approved, and there is not a significance difference in the presence between male and female subjects.

There were two more contingency tables, both considering how many times the ball was dropped, one for the complete track and one focused on the stimuli events on the path. In both cases male subjects have a better performance, dropping the ball less times on the path and when the events happen, this performance has an accuracy of 95%. Based on this information, it is shown in this research that male subjects have a better balance and coordination in virtual environments, while analyzing the complete path and when there are different stimuli to distract the subject, in both cases the male subjects had a better control on the ball to not drop it while going through the path.

6.2 T-Test

As a summary for the data obtained from the different t test, Table 6.2 shows the P-value and observations from the different analyzed variables. Each of the analysis were made comparing the performance between male and female subjects, where a P-value lower than 0.05 represents a significant difference between the male and female subjects in the respective variable.

Table 6.2 Summary of T Test

	P-Value	Observations
Track Time [secs]	0.958	There is no significant difference between male and female subjects.
Reset Ball Time [secs]	0.325	There is no significant difference between male and female subjects.
Balancing Time [secs]	0.994	There is no significant difference between male and female subjects.
Ball Drop on the complete path [score]	0.172	There is no significant difference between male and female subjects.
Ball Drop during the events [score]	**0.013**	Male subjects drop less the ball during the stimuli events.
Av. Ball Speed [m/s]	0.125	There is no significant difference between male and female subjects.
Delta Ball Speed [m/s]	0.601	There is no significant difference between male and female subjects.

The t test was used between the male and female subjects, analyzing the track time, the time to reset the ball, the effective time balancing the ball in the path, how many times the ball was dropped (in the complete path and during the specific events), the average ball speed and the delta ball speed. Considering all the variables, there were not a statistically significant difference in the complete path analysis. The variables with higher difference were the average ball speed and the times that the ball was dropped, but they had a P Value of 0.125 and 0.172 respectively. But there was a variable with a significant difference, this variable was the subjects' performance of dropping the ball during the stimuli events, which had a P Value of 0.013. The sum of all male subjects dropped the ball 21 times during these events, while the female subjects dropped the ball 44 times during the events. This shows that male subjects have a better performance when they balance and coordinate objects in virtual environments, even with distractions.

6.3 Correlation

A summary from the correlation coefficient from the different variables are shown in Table 6.3. This table organizes the correlation in four areas, first the correlation from the presence against the performance variables, on the second place between the videogames skills and the performance variables, on third place between the balance difficulty survey and the actual performance from the subjects, and at last a correlation among the three surveys. The correlation coefficients are shown for male and female subjects, and a more detail explanation from the results is after the table.

Table 6.3 Summary of Correlation

	Male	Female
Male & Female Presence Correlation		
Track Time:	-0.246	-0.045
Balancing Time:	-0.216	-0.167
Drop Ball:	-0.204	-0.127
Av. Ball Speed:	-0.140	-0.093
Male & Female Videogames Correlation		
Track Time:	-0.170	-0.246
Balancing Time:	-0.208	-0.017
Drop Ball:	-0.020	-0.352
Av. Ball Speed:	0.004	-0.333
Male & Female Balance Difficulty Correlation		
Track Time:	-0.019	0.317
Balancing Time:	-0.109	0.127
Drop Ball:	0.200	**0.623**
Av. Ball Speed:	0.245	**0.588**
Male & Female Surveys Correlation		
Presence & Gamer:	0.071	-0.153
Presence & Balance:	0.140	0.121
Gamer & Balance:	0.135	-0.332

The correlation in this research studies the possible relationship between the presence, the subjects' experience playing videogames and the subjects' balance feeling during the experiment against their performance. Subjects' presence did not have a correlation with the performance from the subject, and the videogames experience did not have any relationship either, based on this statistical analysis. But, when the correlation from the subjects perception of the difficulty balancing was made, it was found that this feeling in the female subjects had a correlation with their performance dropping the ball and with the control on the ball speed that they had. The female correlation coefficient between the difficulty level and their performance was of 0.623, while the male coefficient was of 0.200 (to have a correlation it is necessary to have at least a coefficient of 0.5). And, there was a correlation coefficient of 0.588 for female subjects between their feeling balancing the ball and the average ball speed during the experiment, and the male subjects had a 0.245 coefficient in this same correlation.

Based on this correlation analysis, it is possible to say that female subjects have a better interpretation between the virtual environment and the feeling of control. This interpretation helps the female subjects to understand better how good their performance was during the experiment. Even when they had dropped the ball more times.

6.4 Phase Plane

Phase planes are great tools to study specific movements, it is possible to observe if there is a periodic cycle and if there are any kind of disturbances. The problem in this research is that there are sixty subjects, and each subject has its own style to balance the ball and to react to the three different stimuli events. For these reasons the phase planes do not provide insight into human performance in this research. There are no noticeable specific cycles, and there are a lot of disturbances to make balancing the ball difficult. Analyzing all the subjects, it is hard to identify clusters and to decide if there is a significance difference between male and female subjects under this graphic analysis.

6.5 General Conclusions

In chapter I, it is mentioned that the purpose of this research is to measure and compare the human balance and coordination response in virtual environments. The objective is to learn and understand the human balance response in virtual environments. The thesis for this investigation is that it is possible to differentiate male and female subjects when they are balancing an object while they go in a virtual environment trail with obstacles using statistical analysis.

Based on the different analyses mentioned above, it is possible to differentiate male and female subjects when they balance an object while they go through a path in a virtual environment. There is not a statistically significant difference in the presence between male and female subjects, but there is a slightly higher presence in female subjects. If the presence probability limit of 0.1 is used instead of 0.05, female subjects would be considered to have a higher presence. At the moment to consider the complete data from male and female subjects together, there is 80% from all the subjects who experience high presence during the experiment, with an average presence score of 31.5 from a maximum score of 42.

The variable which had an actual difference between the male and female subjects was the dropping the ball variable, where the male subjects had a better performance over the female subjects. Both contingency tables of ball dropping shows that the male subjects have a performance of low dropping of the ball, while female subjects have a medium performance. And, with the t test analysis, male subjects have a significant better performance dropping the ball fewer times during the distraction events that happened in the experiment. But, the correlation analysis shows that female subjects better understood their level of performance, even when they had dropped the ball more times. The female feeling of success or poor performance with the experiment were more strongly related to their actual performance, while the male subjects had not developed this feeling like the female subjects. There was the possibility that the better interpretation from their performance from the female subjects in the experiment were related to their slightly higher presence. But, the correlation coefficient between the presence and the difficulty feeling is 0.121, which means that there is no relation between these two variables.

The thesis from this research is affirmed, because it was proved possible to differentiate male and female subjects when they balance an object while they go through a path in a virtual environment. This was shown with the performance of dropping the ball during the experiment, where male subjects dropped the ball less times. And, it was also found that female subject had a better interpretation of their performance in virtual environments, which was a skill that male subjects did not have. These two points summarize the conclusions, and in the section below some research ideas for future efforts with the existent data are provided.

6.6 Future Research

This research is focused on differentiating the balance and coordination between male and female subjects. To study the balance and coordination, this investigation concentrated on external parameters from the body (e.g. time to complete the track, how many times the ball was dropped, or the ball speed). In addition, the different kind of analysis that were used in this investigation were methods to compare the performance between the male and female subjects.

Another direction that could be taken with the data gathered from this investigation is to observe the body movements from the subjects. This could be done by the position (x, y, z, pitch, yaw, roll) from the head, the dominant hand and non-dominant hand. It is possible to analyze each of these components on its own, or by looking at the interaction with each other. It is possible to try to create a regression study to try to identify if there is a common virtual path followed during the experiment, or to observe the speed reaction from the body at the stimuli events or when the ball is dropped. Another option can be to create a decision tree, which can determine the gender from the subject, based on his or her performance. These are some of the examples that can be studied in the future with the existent data from this experiment.

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APPENDIX

APPENDIX A

A. Consent Form & Questionnaire

The University of Texas Rio Grande Valley

INFORMED CONSENT FORM

Study Title: A Study of Human Balance and Coordination using a Head Mounted Display

Principal Investigator:	Alley Butler	Telephone: (956) 665-2534
Other Personnel:	Daniel Gracia De Luna	

Key points you should know

- We are inviting you to be in a research study we are conducting. Your participation is voluntary. This means it is up to you and only you to decide if you want to be in the study. Even if you decide to join the study, you are free to leave at any time if you change your mind.
- Take your time and ask to have any words or information that you do not understand explained to you.
- This study attempts to measure the balance and coordination of male or female subjects in a Virtual Reality Environment which is provided by a Head Mounted Display. This study measures responses over time which may lead to conclusions about human balance and coordination when experiencing obstacles to movement.
- What will you do if you agree to be in the study?
    - For this research study, you will first answer some questions about handedness and about how likely you are to have physical problems in a virtual reality environment. Then you will be placed into a virtual world using a Head Mounted Display. You will be given an orientation to familiarize you with the Virtual Reality system, and then, you will be asked to follow a trail as you encounter obstacles. Finally, you are asked to sit without using the Head Mounted Display to ensure you have time to regain your composure and answer some questions about your experience. It is expected that each session should last approximately 20-30 minutes.
- Can you be harmed by being in this study?
    - Some people experience "Simulator Sickness" when exposed to immersive environments. Simulator Sickness is similar to motion sickness, and our response if you

experience Simulator Sickness is to suspend the test and allow you to recover. Simulator sickness is relatively rare.

- An incident of Simulator Sickness is cured by simply suspending the experiment and allowing the test subject to recover, usually in 15-20 minutes.
- Another potential risk is loss of balance and falling. To prevent this event from happening, you will be watched closely by the research team member conducting the experiment. If you begin to fall over, the research team member catch you and prevent a potentially harmful fall.
- Risks to your personal privacy and confidentiality: Your participation in this research will be held strictly confidential and only a code will be used to identify your stored data.

- Will you get anything for being in this study?
    - You will receive $10.00 an hour for participating in the study. This compensation is provided in the form of a check available within a few weeks after participation from Ms. Elizabeth Rodriguez in the MANE department.
    - Please note, any payments you receive is considered income for tax purposes. Additional information may be required at the time of receipt. You must show a picture ID and sign for your check when you receive it.
- Could you be taken out of the study?
    - You could be removed from the study if:
        - You have a history of Simulator Sickness
        - You are visually impaired, or
        - You have an impairment involving locomotion

Can the information we collect be used for other studies?

We will not use or distribute information you gave us for any other research by us or other researchers in the future.

What happens if I say no or change my mind?

- You can say you do not want to be in the study now or if you change your mind later, you can stop participating at any time.
- No one will treat your differently. You will not be penalized.

How will my privacy be protected?

- Your information will be stored with a code instead of identifiers (such as name, date of birth, email address, etc.). Instead of using the names of the participants, names will be replaced with a code number.
- The data is kept in a locked office in a cabinet.
- No published scientific reports will identify you directly. Your responses may be quoted in whole or in part in publications or presentations about the research. If quotes are used, your real

name is replaced by a made up name (pseudonym) and any additional information that might directly identify you is removed.

Who to contact for research related questions

For questions about this study or to report any problems you experience as a result of being in this study contact Dr. Alley C. Butler at 956-665-2534 or alley.butler@utrgv.edu.

Who to contact regarding your rights as a participant

This research has been reviewed and approved by the University of Texas Institutional Review Board for Human Subjects Protections (IRB). If you have any questions about your rights as a participant, or if you feel that your rights as a participant were not adequately met by the researcher, please contact the IRB at (956) 665-2093 or irb@utrgv.edu.

Signatures

By signing below, you indicate that you are voluntarily agreeing to participate in this study and that the procedures involved have been described to your satisfaction. The researcher will provide you with a copy of this form for your own reference. To participate, you must be at least 18 years of age. If you are under 18, please inform the researcher.

____ ____/_____/______

Participant's Signature Date

Study Questionnaire

Some people get nauseous and disoriented when placed in a virtual environment. This is often referred to as Simulator Sickness because this occurred first in the use of flight simulators. Have you ever experienced Simulator Sickness? Please circle Yes or No below.

Yes No

This study employs an HTC Vive Head Mounted Display or HMD. To use the HMD properly, you will need normal vision. Do you have any visual impairments? Please circle Yes or No below.

Yes No

This study involves balance and coordination in a virtual environment in response to obstacles that you should experience. To provide useful data, you should have normal locomotion (i.e. no difficulties walking or moving on both feet). Do you have an impairment in locomotion? Please circle Yes or No below.

Yes No

Subject Number: ________________

APPENDIX B

B1. Recruitment Flyer

Wanted: Paid Test Subjects

Experiments in Immersive Virtual Environments

Pay is $10/hour

Convenient schedule

Campus location

Contact the researchers at:

immersive-test@utrgv.edu

B2. E-mail Recruitment Template

The University of Texas Rio Grande Valley

Email Recruitment

Hello,

My name is Daniel Gracia De Luna; I am a graduate student at the Department of Manufacturing and Industrial Engineering at the University of Texas Rio Grande Valley (UTRGV). I would like to invite you to participate in my research study to examine human balance and coordination in a virtual environment.

This research study has been reviewed and approved by the Institutional Review Board for the Protection of Human Subjects (IRB) at the University of Texas Rio Grande Valley.

In order to participate you must be 18 years or older. Participation in this research is completely voluntary, you may choose not to participate without penalty.

As a participant, you will be asked to complete a questionnaire and consent form, learn how to navigate in a Head Mounted Display virtual reality environment, undergo a test of your balance and coordination in the virtual environment, and take time to recover. This activity should take about an hour or less to complete. All data is treated as confidential.

If you would like to participate in this research study, reply and let me know of your interest. The pay for student participants is $10 per hour.

If you have questions related to the research, please contact me by email at immersive-test@utrgv.edu.

Thank you for your cooperation!

Daniel Gracia De Luna

B3. Telephone Recruitment Protocol

The University of Texas Rio Grande Valley

Telephone Script

Hello, my name is Daniel Gracia De Luna. I am a graduate student at The University of Texas Rio Grande Valley (UTRGV).

My advisor and I are involved in a research study. The purpose of our study is better understand human balance and coordination by using a virtual environment. With your consent, I would like to discuss participation in our study. We would like to pay you for your time and participation.

In our study, your identity and responses are completely anonymous. I will not record any identifiers that can be linked to your responses or participation in this study. All participants are assigned a subject number for reporting purposes, but this number is not be associated with your personal identity.

Some people get a condition known as Simulator Sickness, in which there is mild nausea (like sea sickness) or disorientation. Very few people get Simulator Sickness, and the cure for Simulator Sickness is that we suspend the test and let you recover. Most people recover nicely after about 10 or 15 minutes of rest. There are no other expected risks to you for helping me with this study. There are also no expected benefits for you either, except for the pay and opportunity to be involved in a study with virtual environments.

Do you have any questions now? If you have questions later, please contact me by email at immersive-test@utrgv.edu.

You may also contact my faculty advisor Dr. Alley Butler, at 956-665-2534.

Would you agree to participate in this study?

APPENDIX C

Presence Survey

1. Please rate your sense of being walking on the path, from 1 to 7, where the 7 represents your normal experience of being in a place. I had a sense of "being there" walking on the path...

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

2. To what extent were there times during the experience when the path was the reality for you? There were times during the experience when the path was the reality for me...

At no time. 1 2 3 4 5 6 7 Almost all the time

3. When you think back about your experience, do you think of the path more as images that you saw, or more as somewhere that you visited? The path seems to me to be more like...

Images that I saw. 1 2 3 4 5 6 7 Somewhere that I visited.

4. During the time of the experience, which as strongest on the whole, your sense of being in the path, or of being elsewhere? I had a stronger sense of...

Being elsewhere. 1 2 3 4 5 6 7 Being in the path.

5. Consider your memory of being in the path. How similar in terms of structure of the memory is this to the structure of the memory of other places you have been today? By “structure of the memory,” consider things like the extent to which you have a visual memory of a walking path, whether that memory is in color, the extent to which the memory seems vivid or realistic, its size, location in your imagination, and other such structural elements. I think of the office space as a place in a way similar to other places that I’ve been today…

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

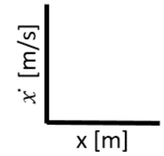
6. During the time of the experience, did you often think to yourself that you were actually in a walking path? During the experience I often though that I was really standing in the walking path…

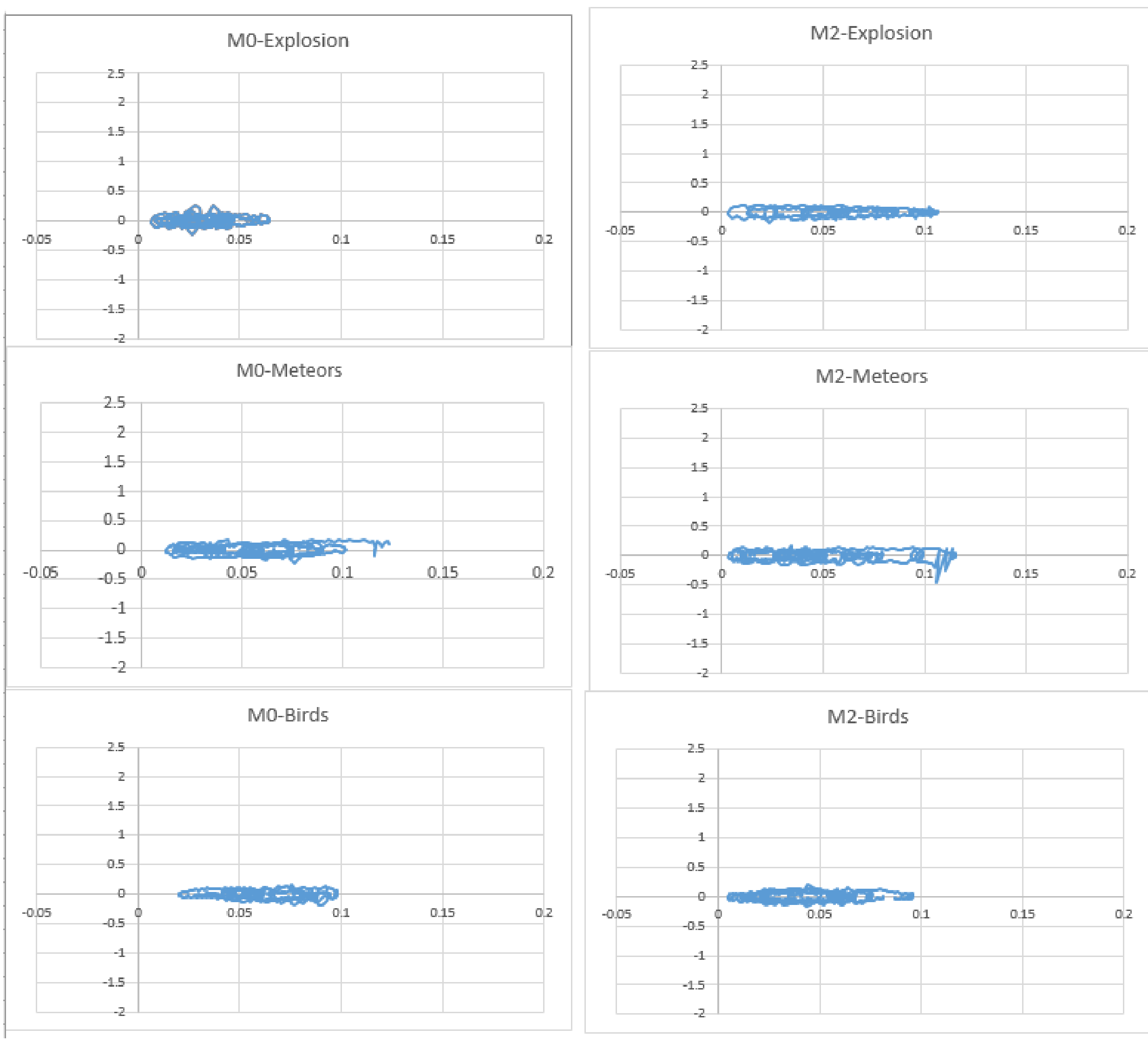
Not very often. 1 2 3 4 5 6 7 Very much so.

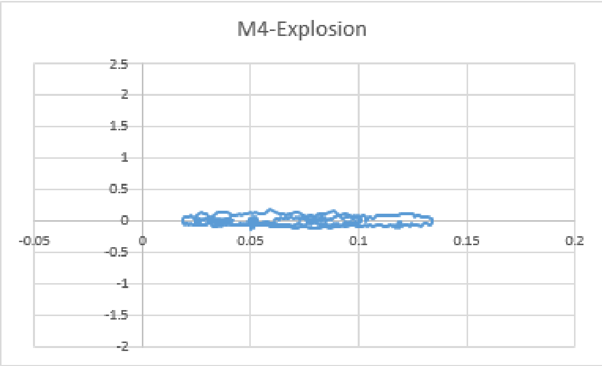
APPENDIX D

Phase Planes

Male Subjects



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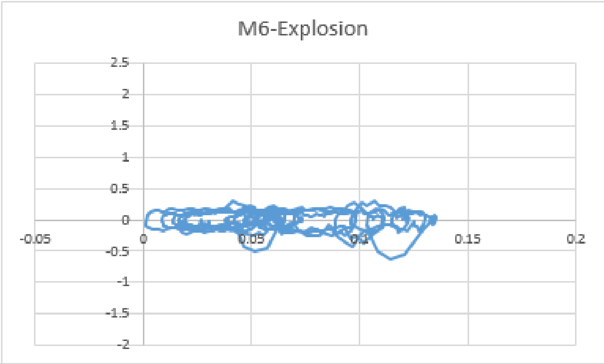
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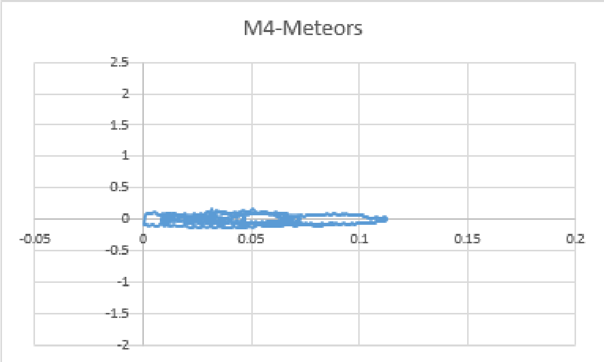
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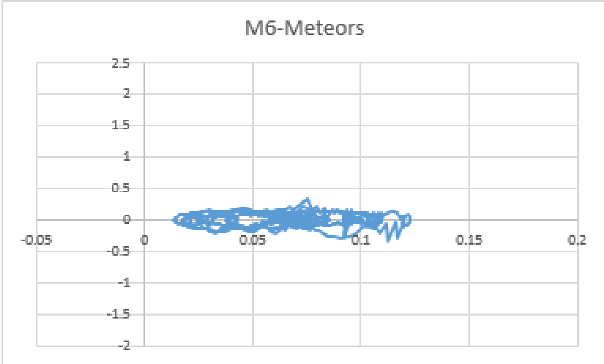
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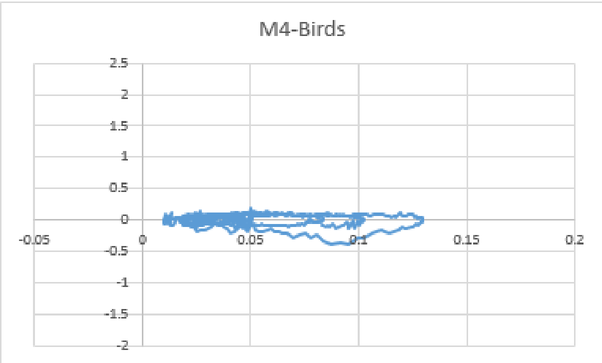
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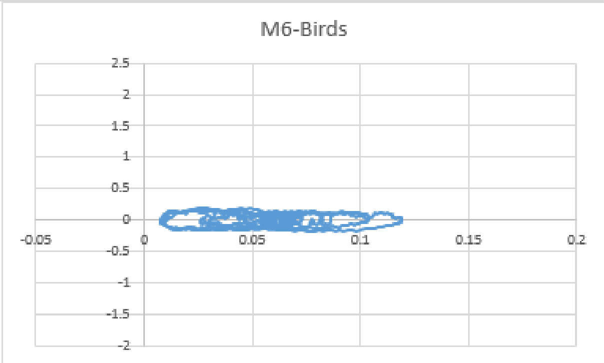
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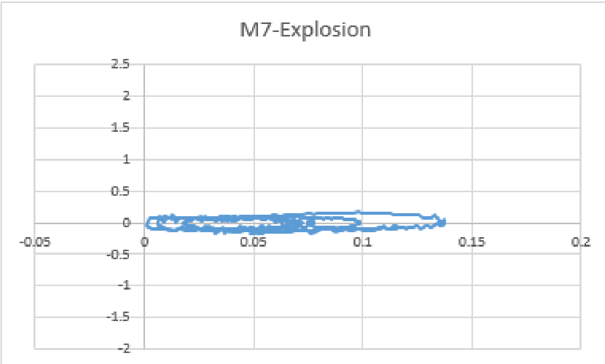
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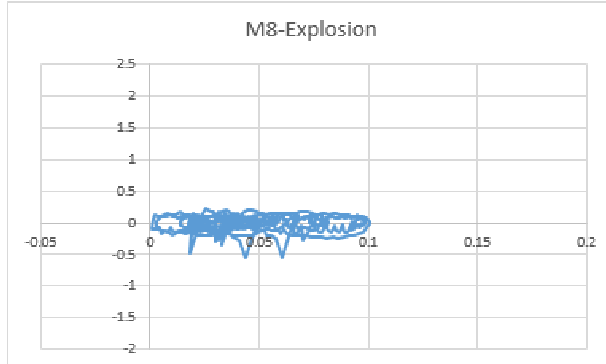
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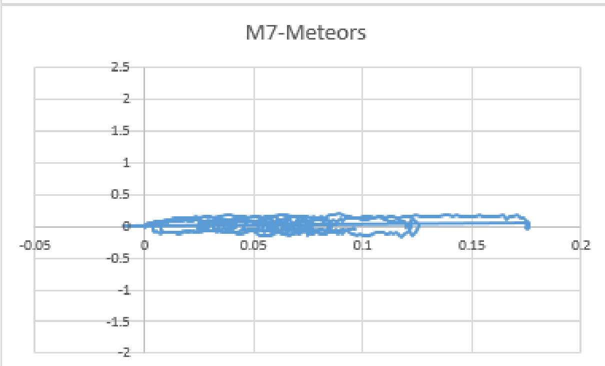
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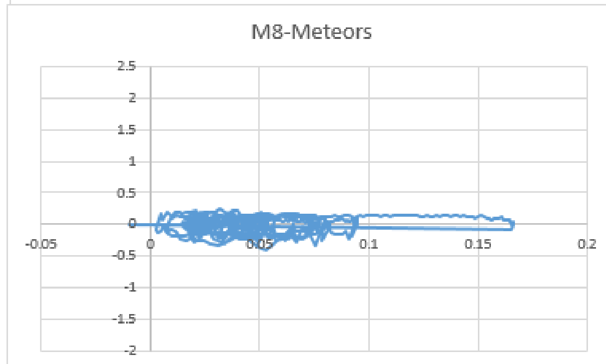
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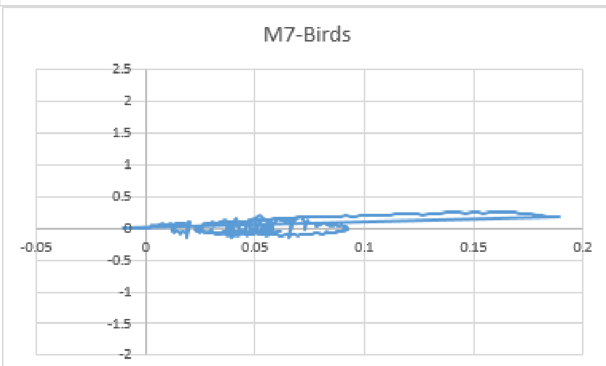
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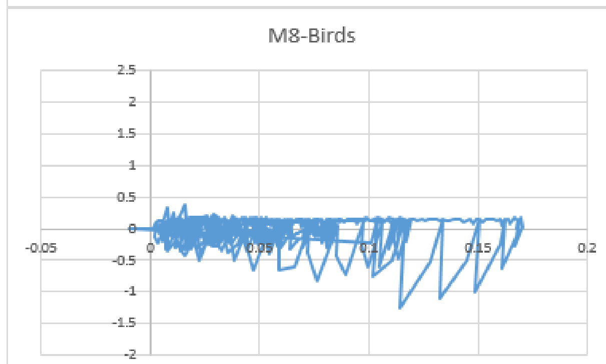
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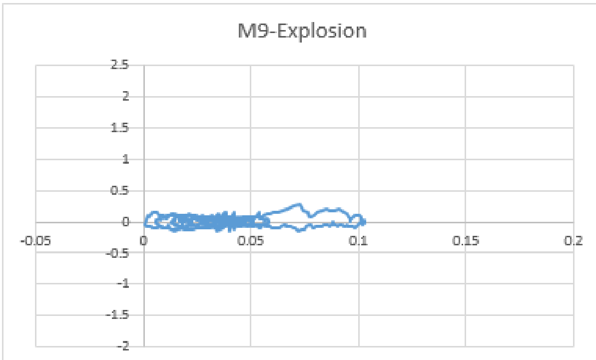
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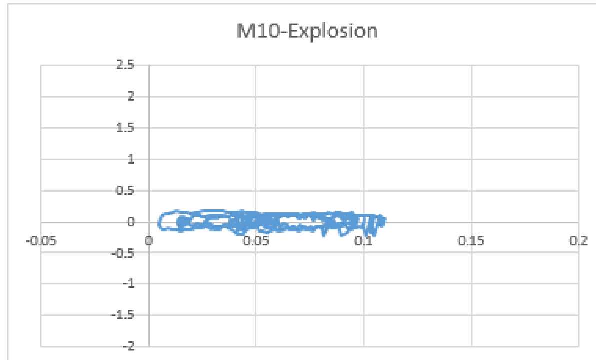
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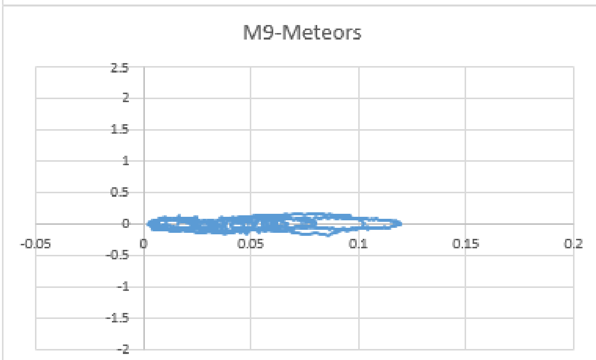
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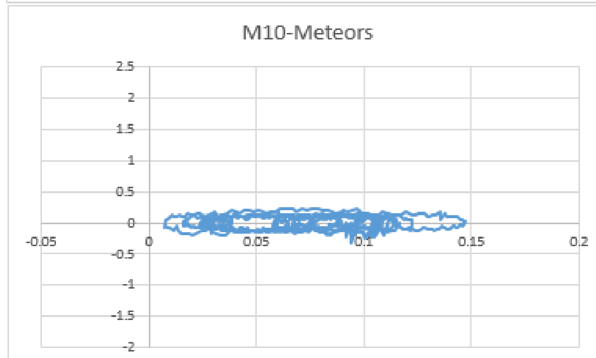
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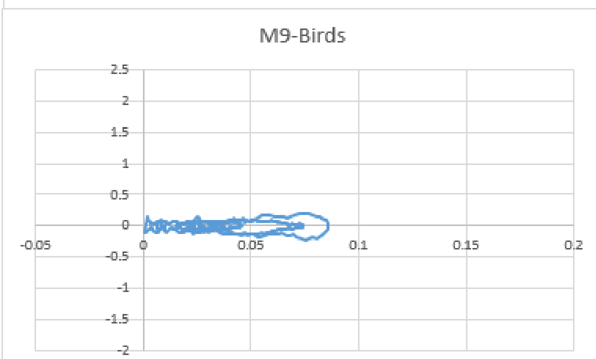
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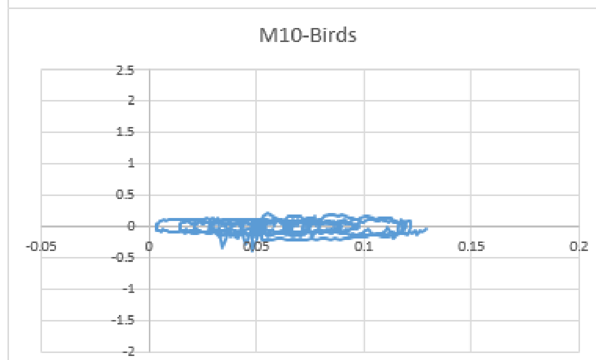
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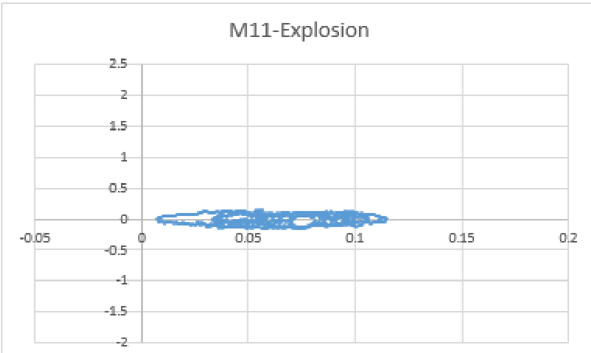
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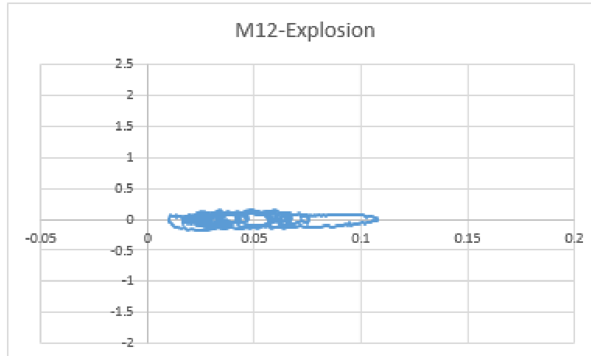
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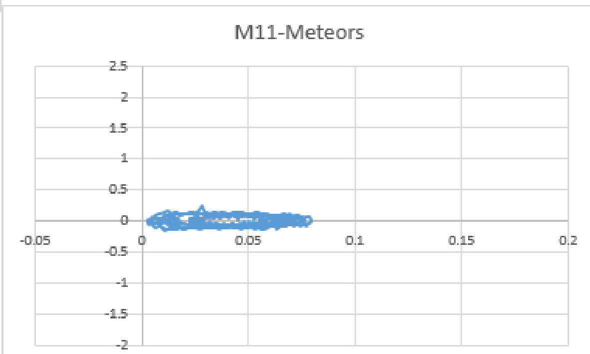
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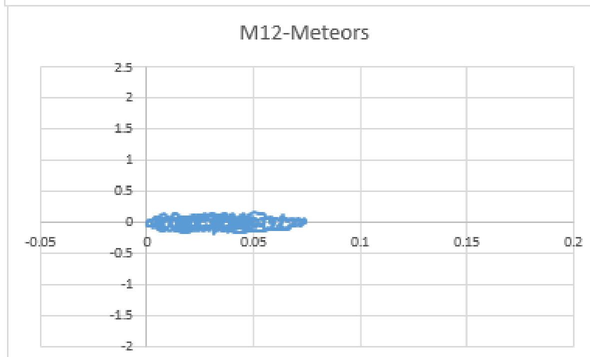
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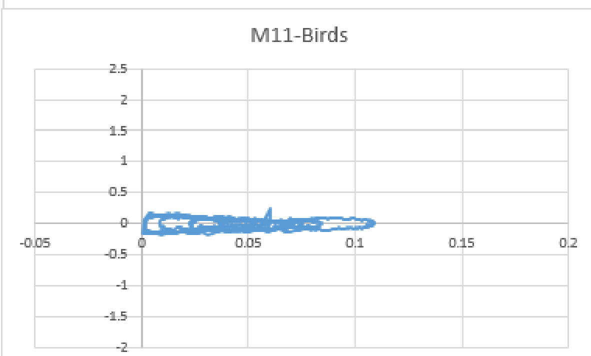
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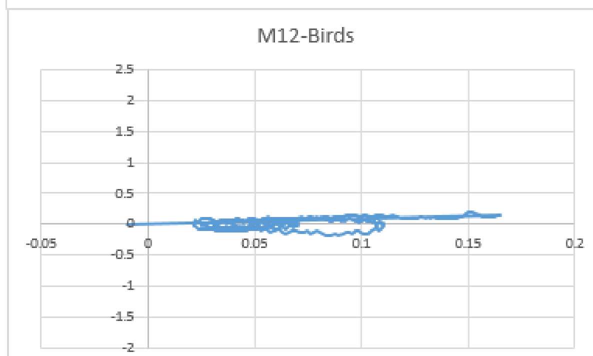
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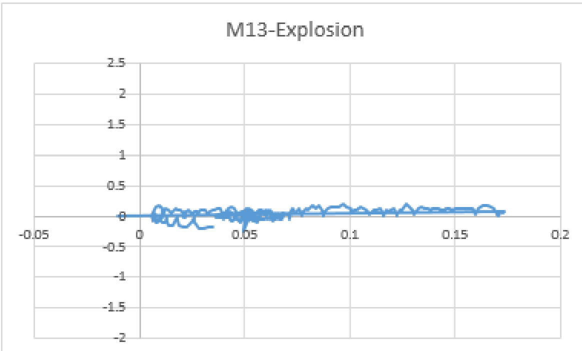
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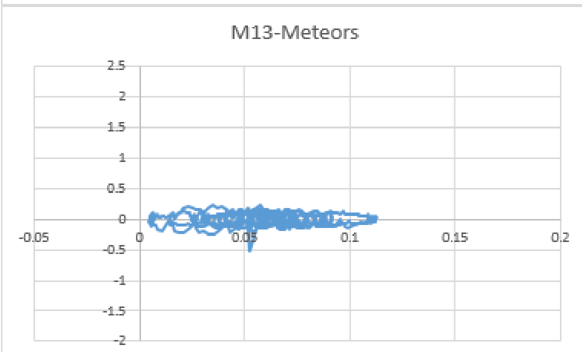
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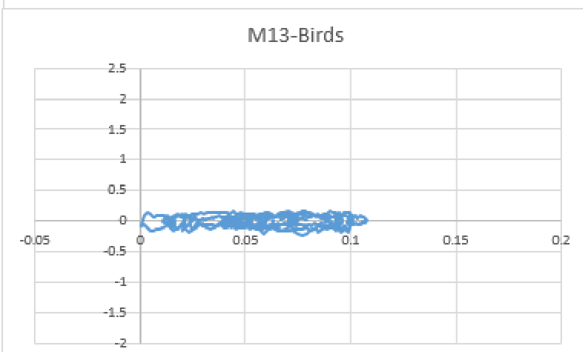
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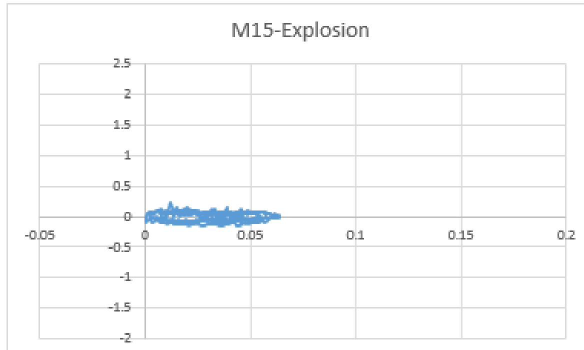
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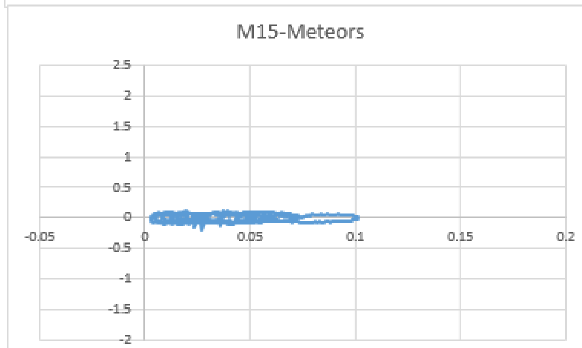
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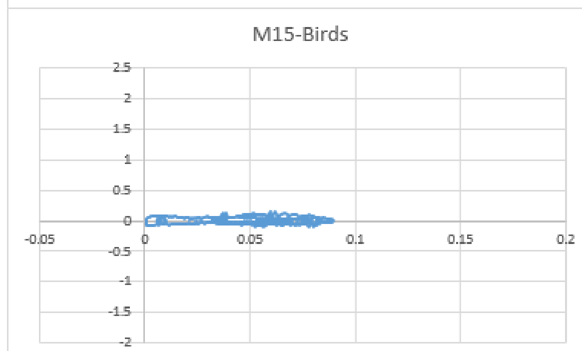
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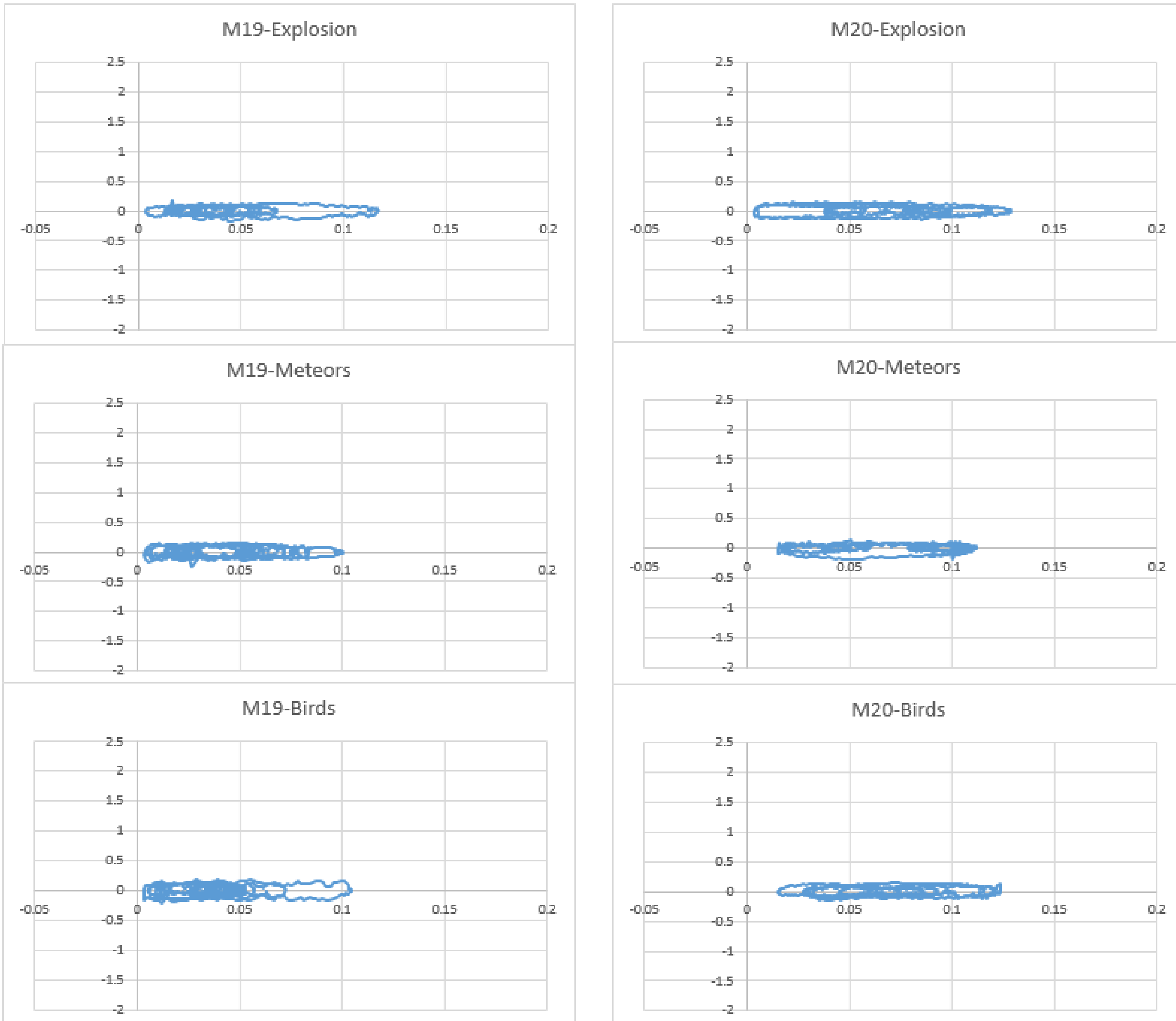
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M20-Explosion
M19-Meteors
M20-Meteors
M19-Birds
M20-Birds
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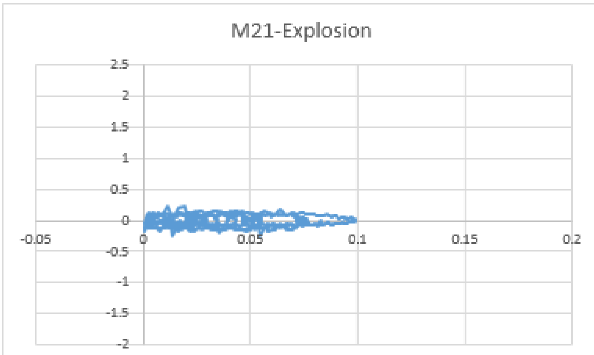
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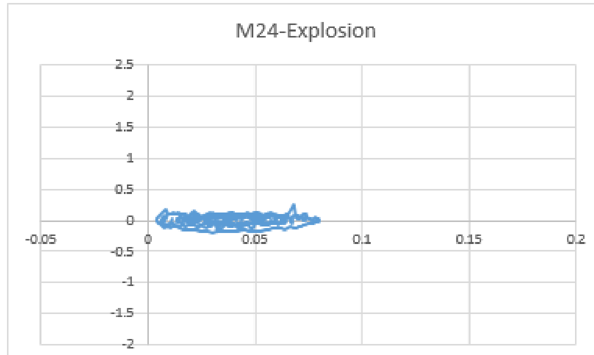
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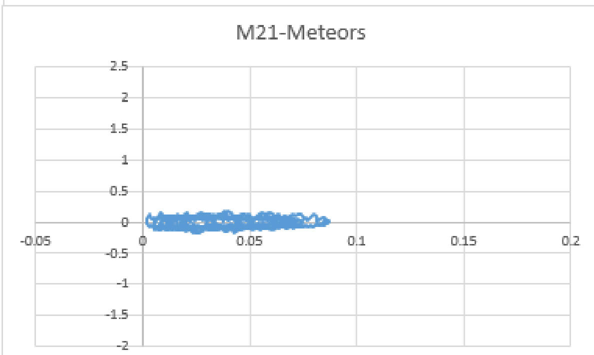
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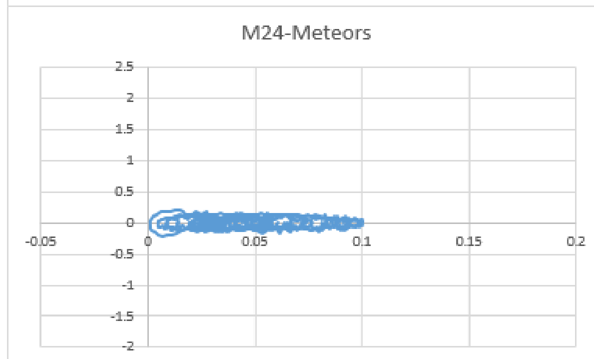
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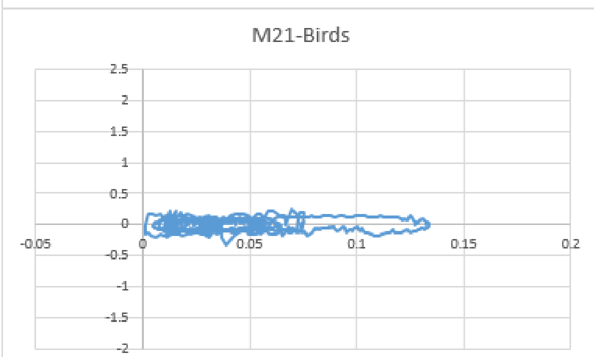
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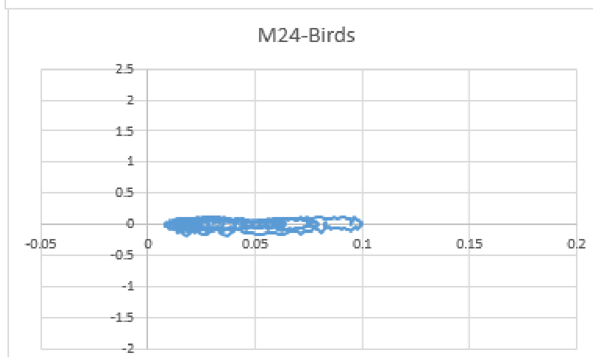
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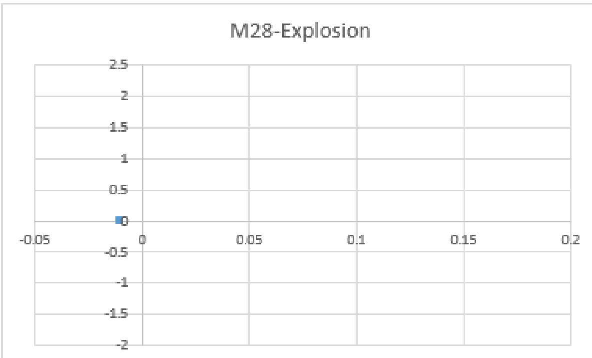
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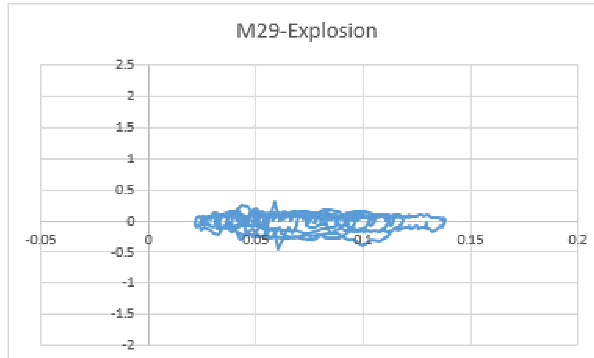
M29-Explosion
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1.5
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-1
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-2
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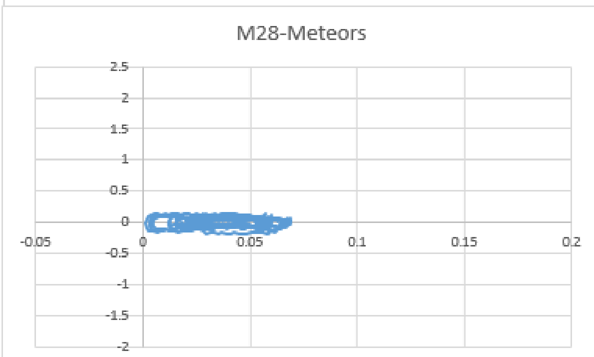
0.05
0.1
0.15
0.2


M28-Meteors
2.5
2
1.5
1
0.5
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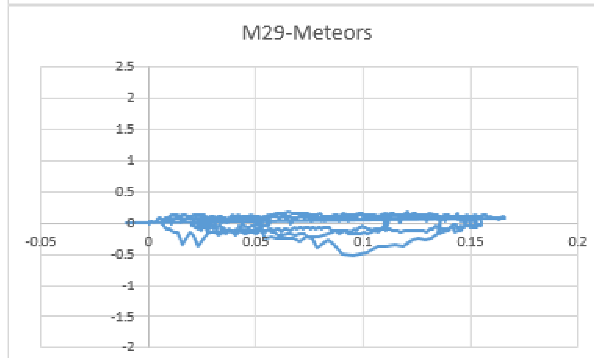
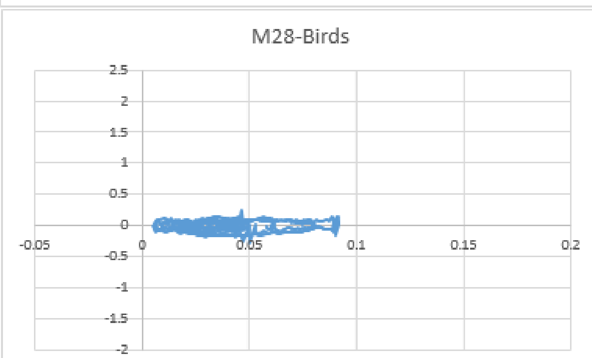
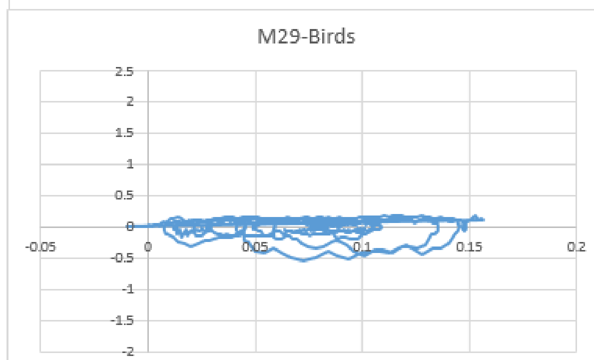
-0.5
-1
-1.5
-2
-0.05
0
0.05
0.1
0.15
0.2


M29-Meteors
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-0.05
0
0.05
0.1
0.15
0.2


M28-Birds
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-0.05
0
0.05
0.1
0.15
0.2


M29-Birds
2.5
2
1.5
1
0.5
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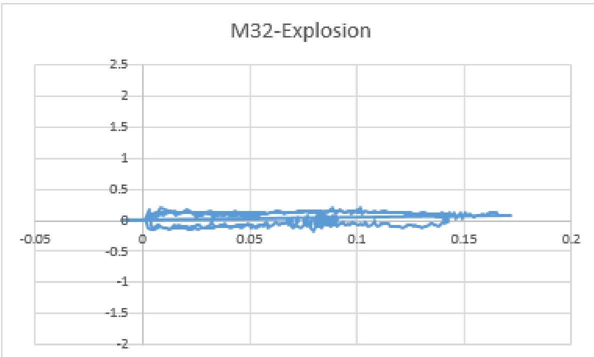
-0.5
-1
-1.5
-2
-0.05
0
0.05
0.1
0.15
0.2


M32-Explosion
2.5
2
1.5
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0.5
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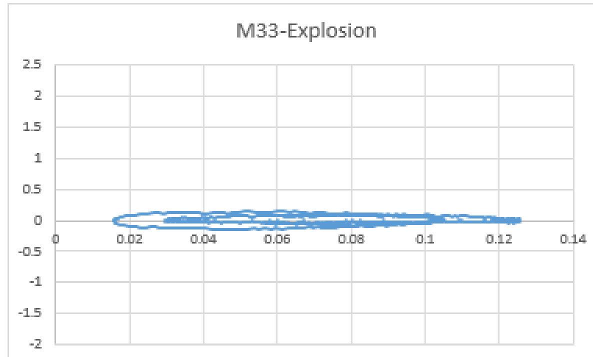
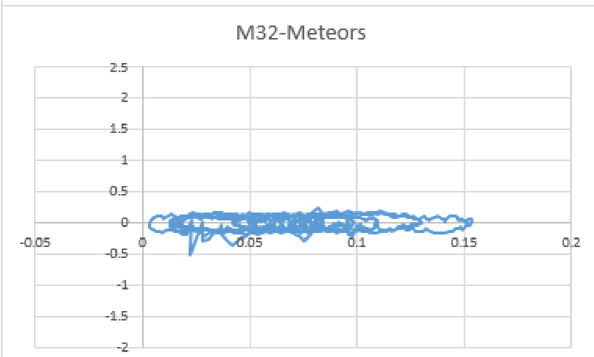
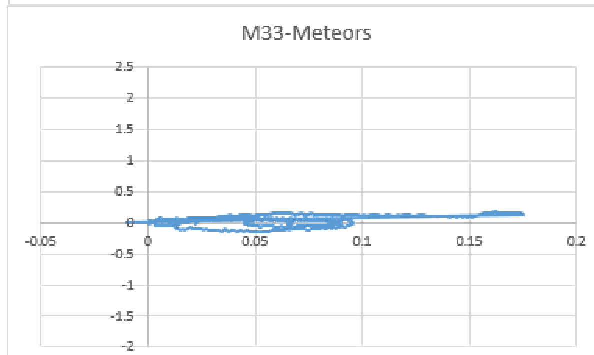
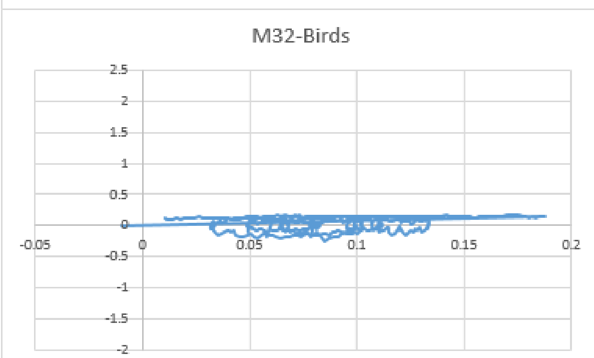
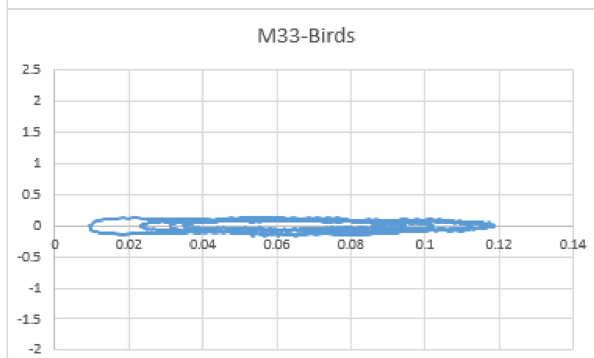
-0.5
-1
-1.5
-2
-0.05
0
0.05
0.1
0.15
0.2

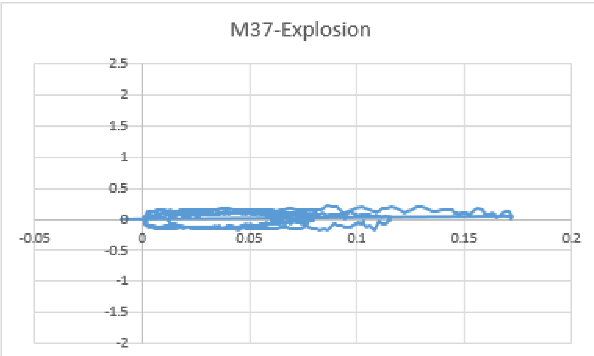

M33-Explosion
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14

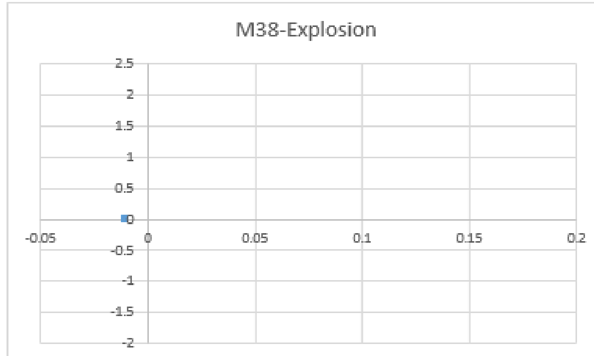

M32-Meteors
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-0.05
0
0.05
0.1
0.15
0.2

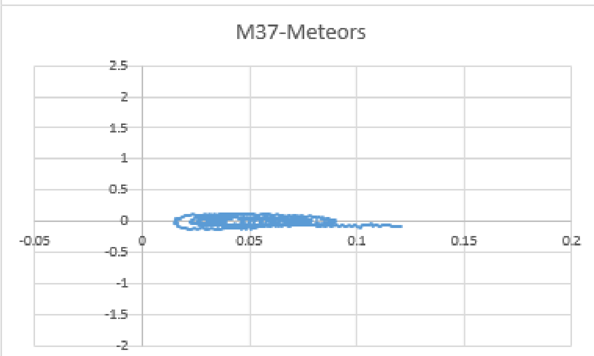

M33-Meteors
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-0.05
0
0.05
0.1
0.15
0.2

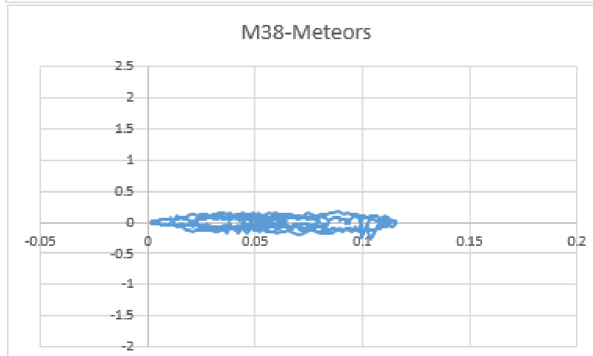

M32-Birds
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-0.05
0
0.05
0.1
0.15
0.2

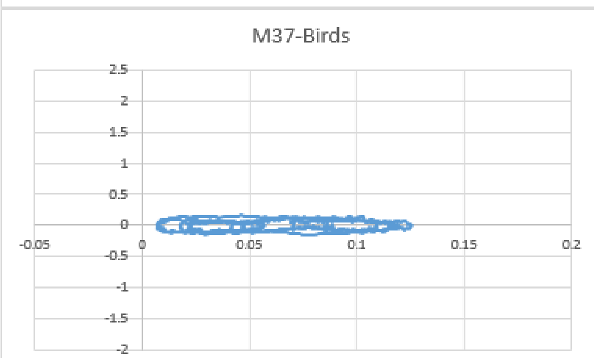

M33-Birds
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14

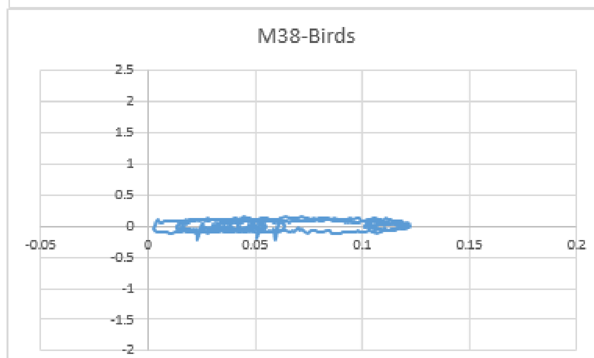

M37-Explosion
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-0.05
0
0.05
0.1
0.15
0.2

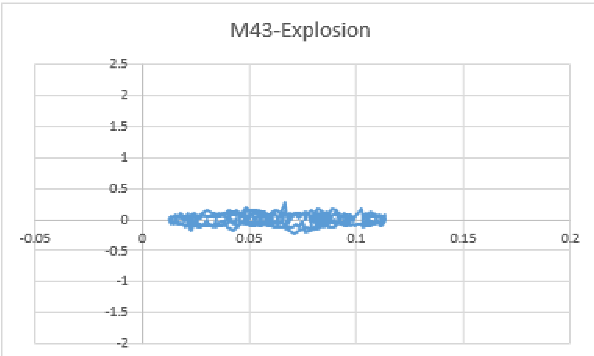

M38-Explosion
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-0.05
0
0.05
0.1
0.15
0.2

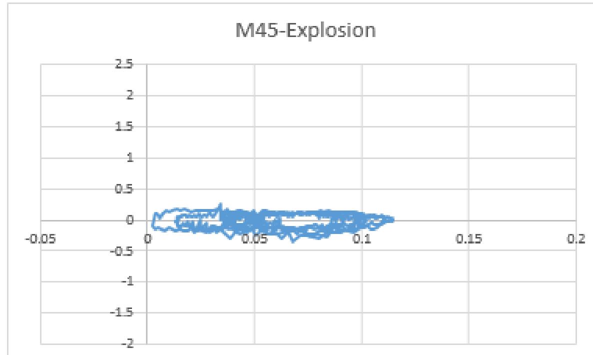

M37-Meteors
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-0.05
0
0.05
0.1
0.15
0.2

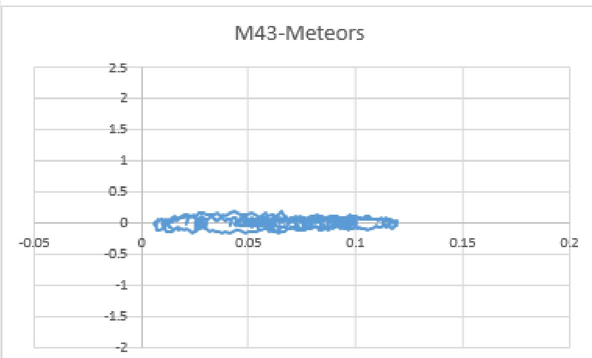

M38-Meteors
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-0.05
0
0.05
0.1
0.15
0.2

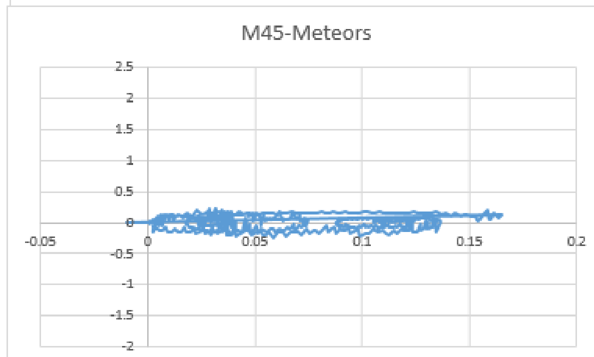

M37-Birds
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-0.05
0
0.05
0.1
0.15
0.2

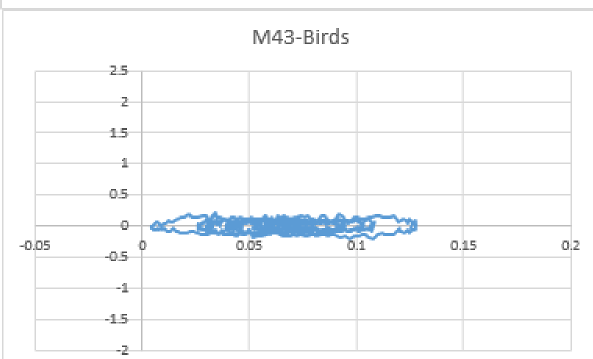

M38-Birds
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-0.05
0
0.05
0.1
0.15
0.2

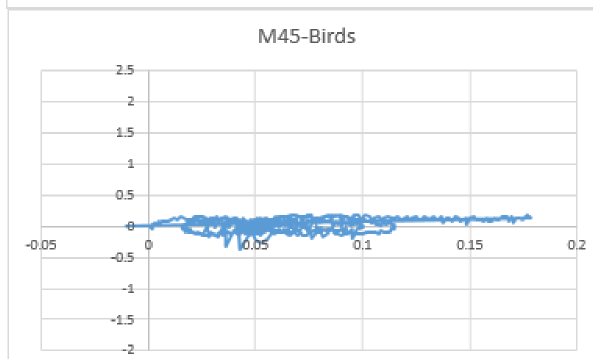

M43-Explosion
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-0.05
0
0.05
0.1
0.15
0.2

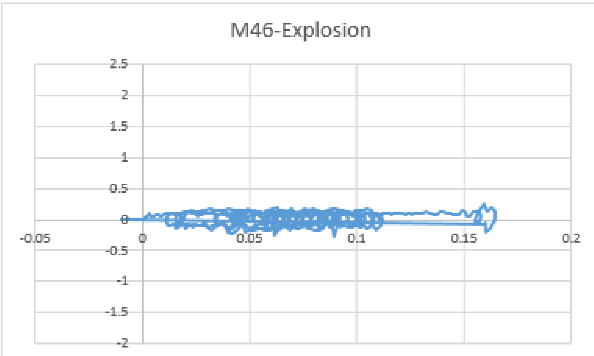

M45-Explosion
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-0.05
0
0.05
0.1
0.15
0.2

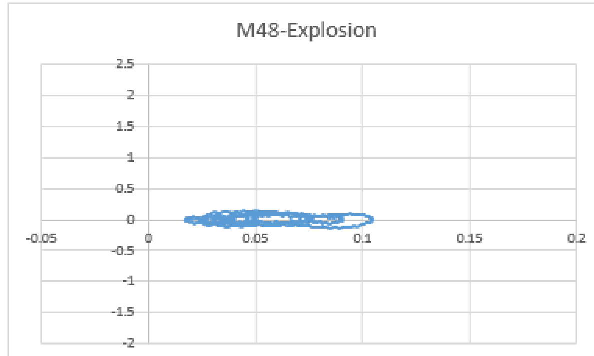

M43-Meteors
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-0.05
0
0.05
0.1
0.15
0.2

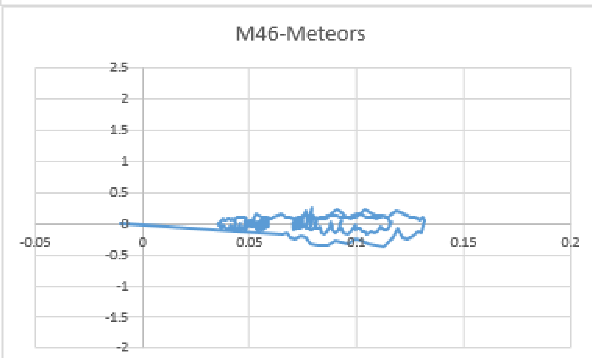

M45-Meteors
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-0.05
0
0.05
0.1
0.15
0.2

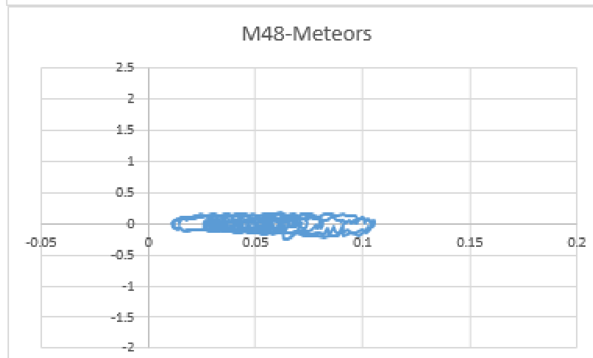

M43-Birds
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-0.05
0
0.05
0.1
0.15
0.2

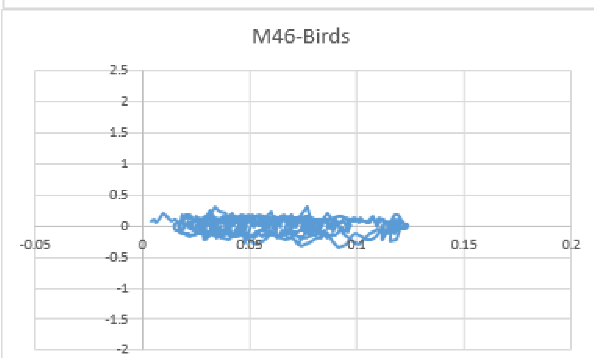

M45-Birds
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-0.05
0
0.05
0.1
0.15
0.2

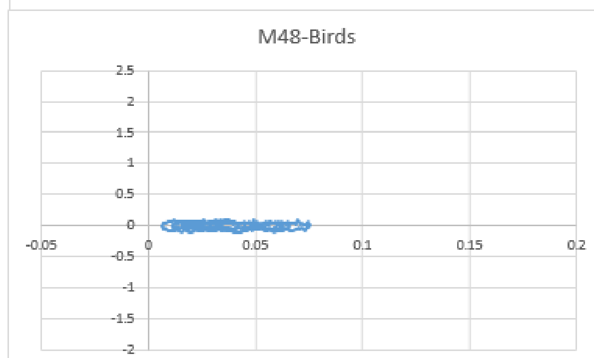

M46-Explosion
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-0.05
0
0.05
0.1
0.15
0.2

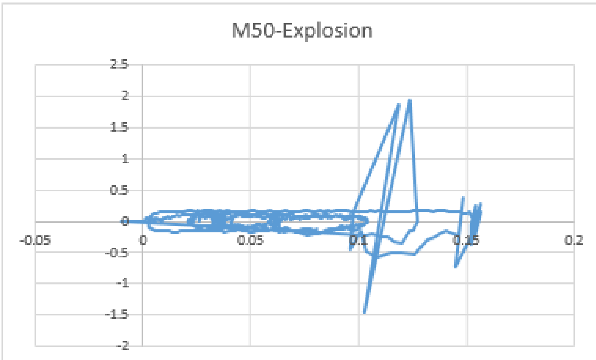

M48-Explosion
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-0.05
0
0.05
0.1
0.15
0.2

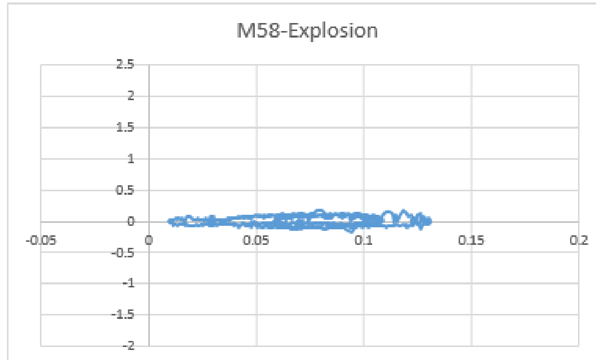

M46-Meteors
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-0.05
0
0.05
0.1
0.15
0.2

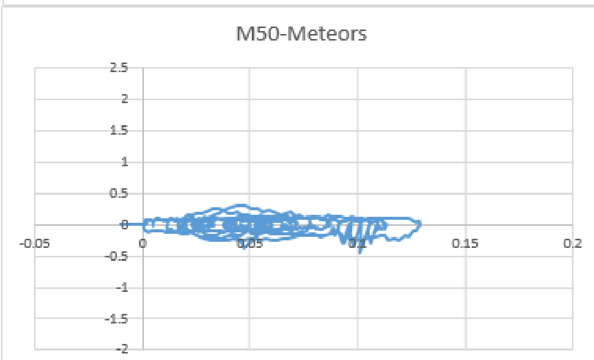

M48-Meteors
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-0.05
0
0.05
0.1
0.15
0.2

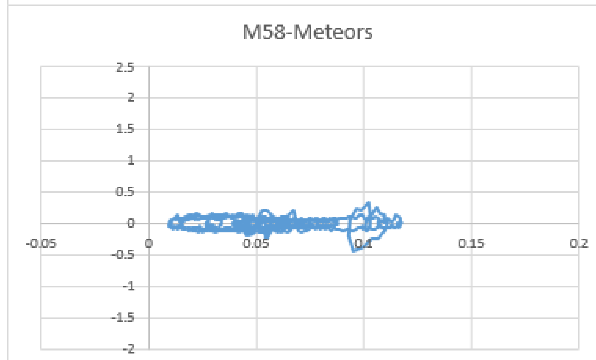

M46-Birds
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-0.05
0
0.05
0.1
0.15
0.2

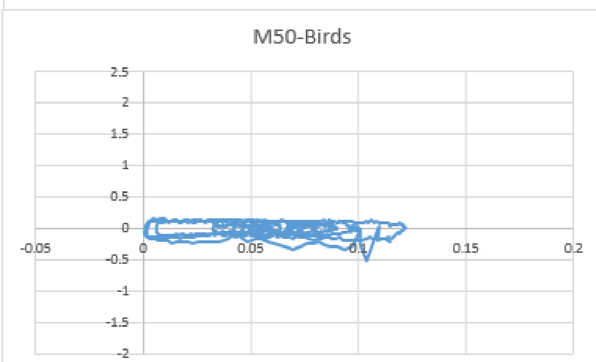

M48-Birds
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-0.05
0
0.05
0.1
0.15
0.2

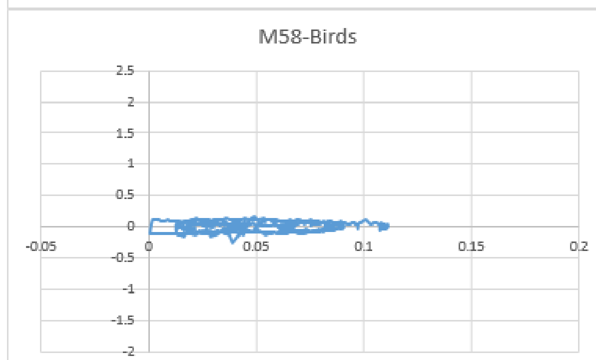

M50-Explosion
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-0.05
0
0.05
0.1
0.15
0.2

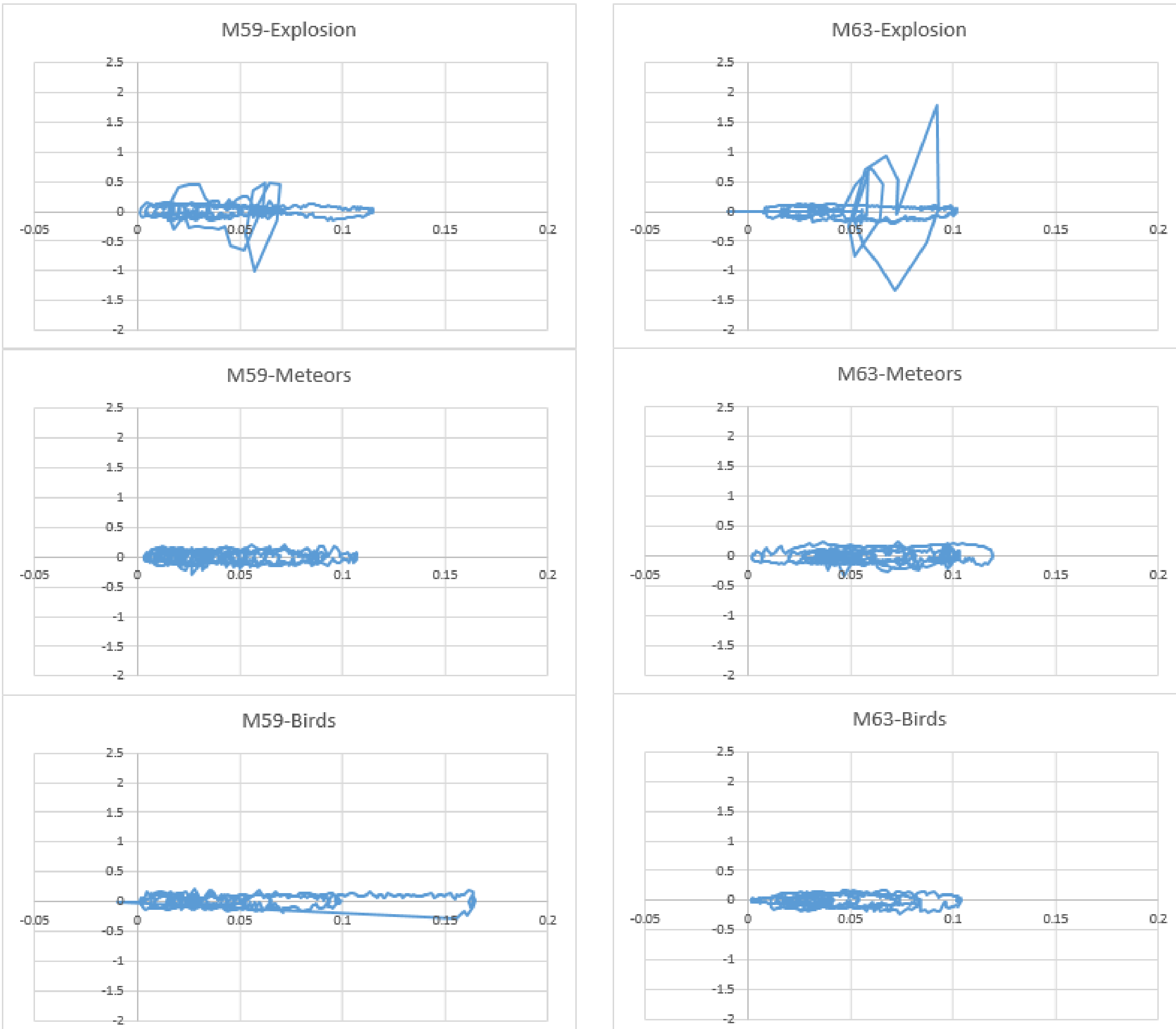

M58-Explosion
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-0.05
0
0.05
0.1
0.15
0.2


M50-Meteors
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-0.05
0
0.05
0.1
0.15
0.2

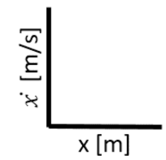

M58-Meteors
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-0.05
0
0.05
0.1
0.15
0.2

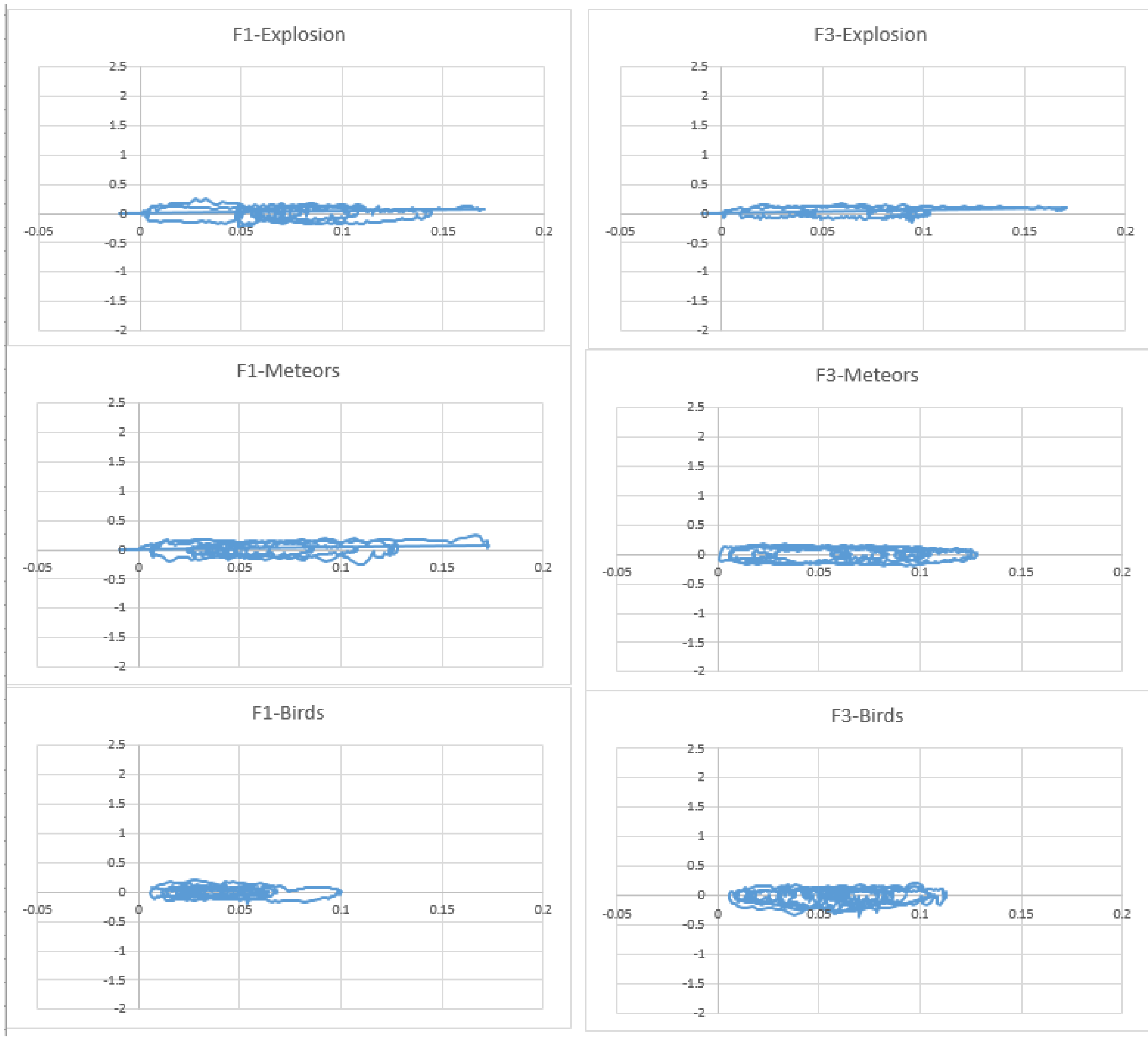

M50-Birds
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-0.05
0
0.05
0.1
0.15
0.2

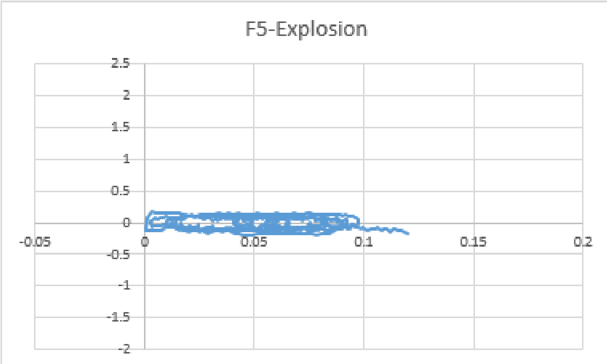

M58-Birds
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-0.05
0
0.05
0.1
0.15
0.2

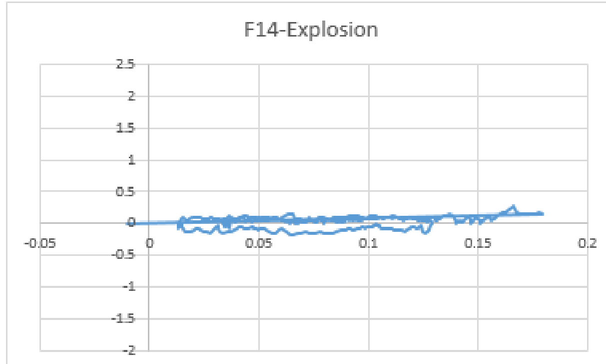

M59-Explosion
M63-Explosion
M59-Meteors
M63-Meteors
M59-Birds
M63-Birds
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-0.05
0
0.05
0.1
0.15
0.2

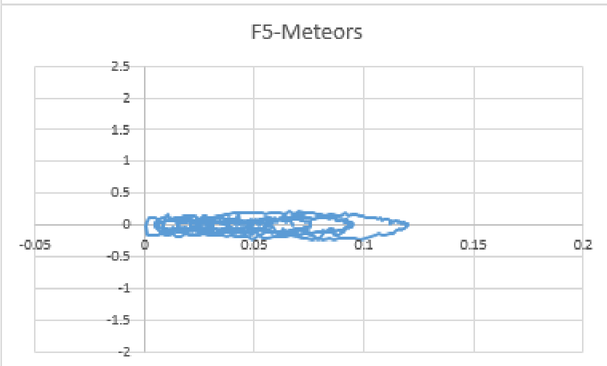
Female Subjects:

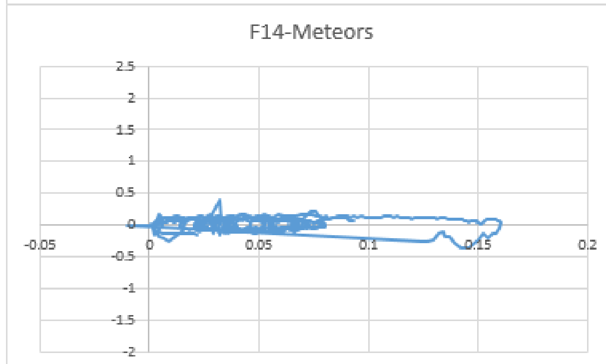


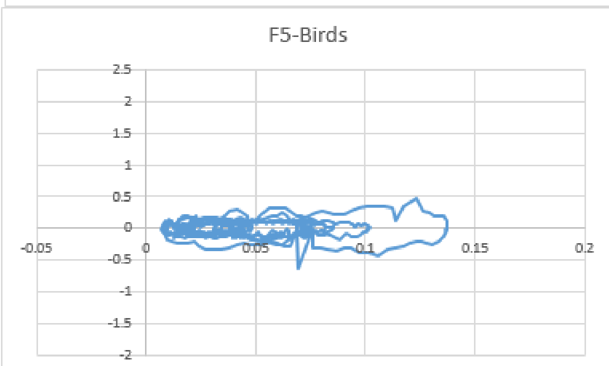


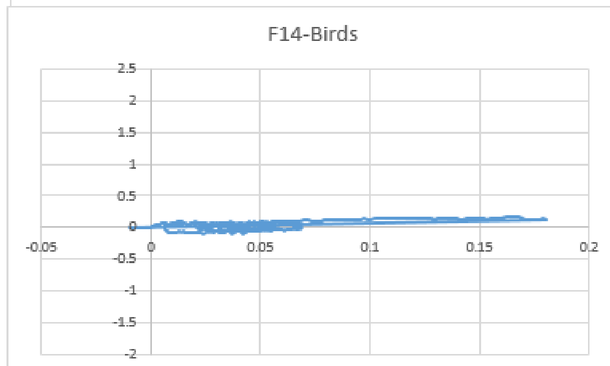

F5-Explosion
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-0.05
0
0.05
0.1
0.15
0.2

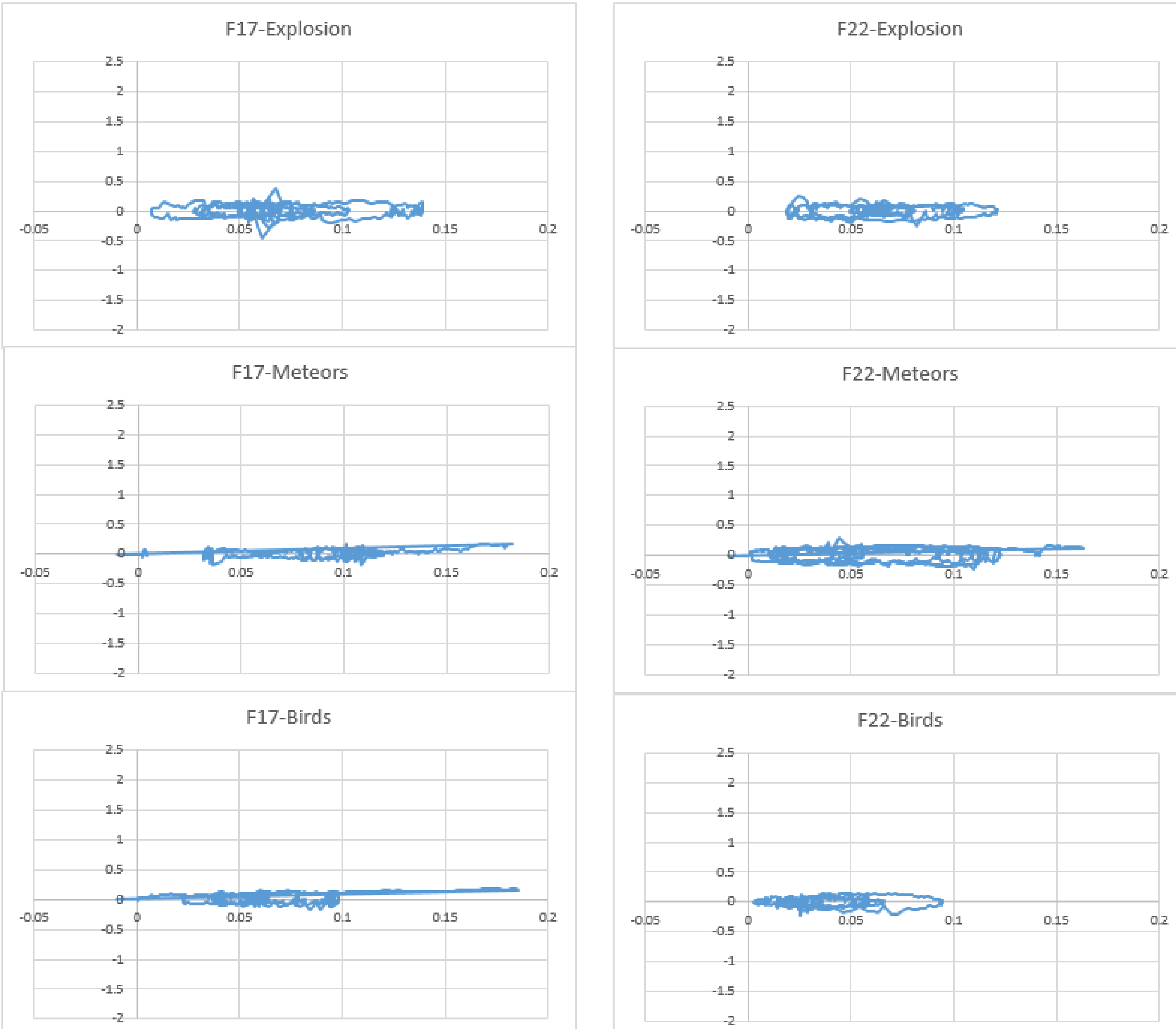

F14-Explosion
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-0.05
0
0.05
0.1
0.15
0.2

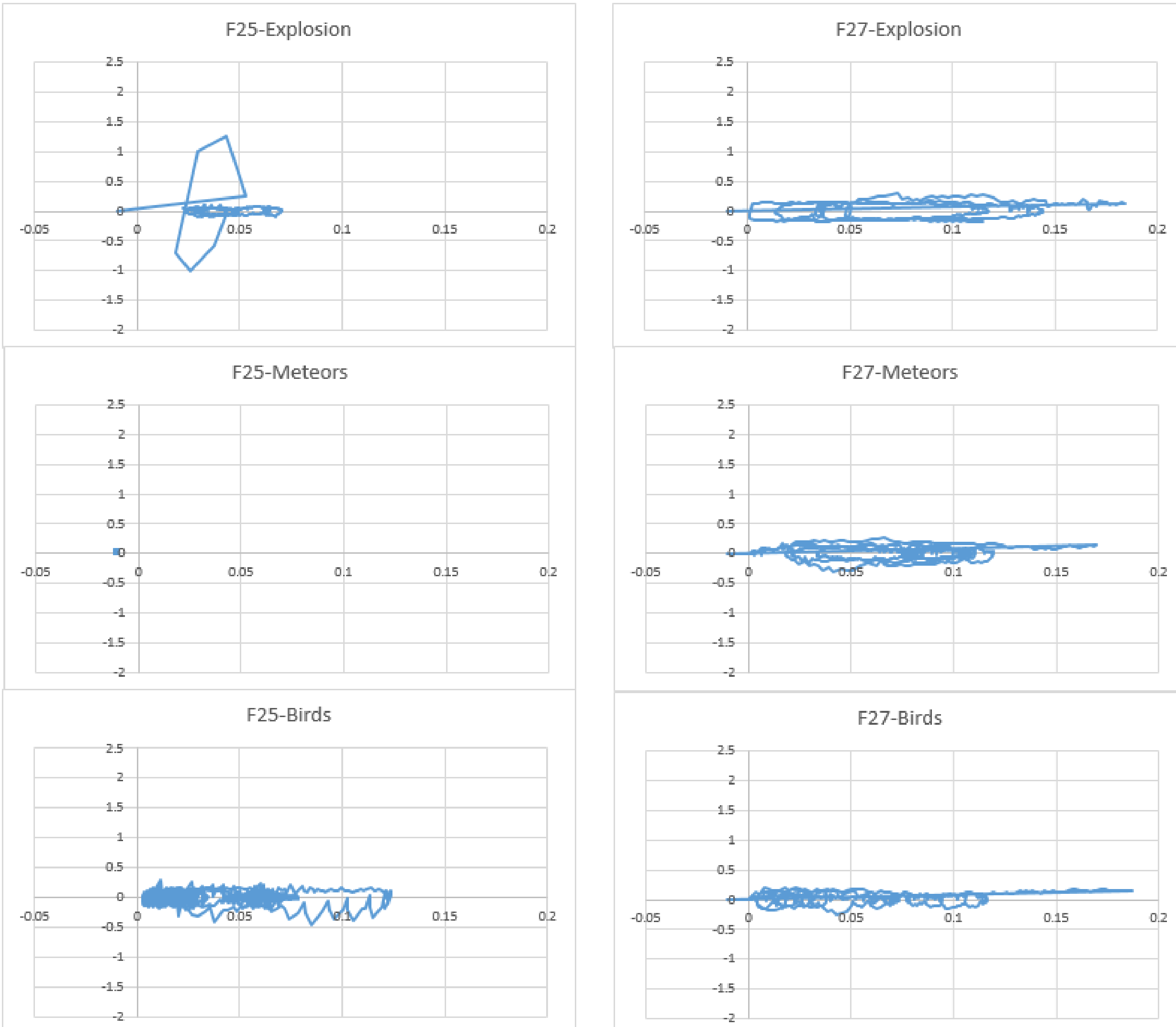

F5-Meteors
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-0.05
0
0.05
0.1
0.15
0.2

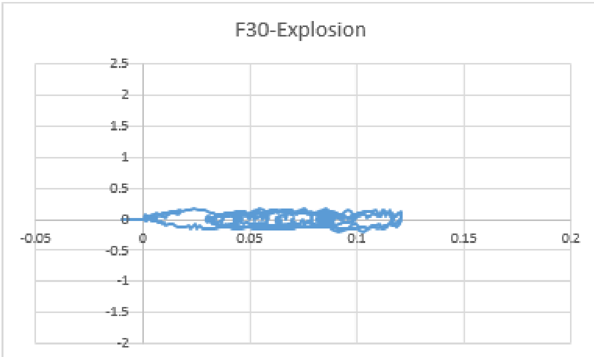

F14-Meteors
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-0.05
0
0.05
0.1
0.15
0.2


F5-Birds
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-0.05
0
0.05
0.1
0.15
0.2


F14-Birds
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-0.05
0
0.05
0.1
0.15
0.2


F17-Explosion
2.5 2 1.5 1 0.5 0 -0.5 -1 -1.5 -2
-0.05 0 0.05 0.1 0.15 0.2
F22-Explosion
2.5 2 1.5 1 0.5 0 -0.5 -1 -1.5 -2
-0.05 0 0.05 0.1 0.15 0.2
F17-Meteors
2.5 2 1.5 1 0.5 0 -0.5 -1 -1.5 -2
-0.05 0 0.05 0.1 0.15 0.2
F22-Meteors
2.5 2 1.5 1 0.5 0 -0.5 -1 -1.5 -2
-0.05 0 0.05 0.1 0.15 0.2
F17-Birds
2.5 2 1.5 1 0.5 0 -0.5 -1 -1.5 -2
-0.05 0 0.05 0.1 0.15 0.2
F22-Birds
2.5 2 1.5 1 0.5 0 -0.5 -1 -1.5 -2
-0.05 0 0.05 0.1 0.15 0.2


F25-Explosion
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-0.05
0
0.05
0.1
0.15
0.2
F27-Explosion
F25-Meteors
F27-Meteors
F25-Birds
F27-Birds


F30-Explosion
2.5
2
1.5
1
0.5
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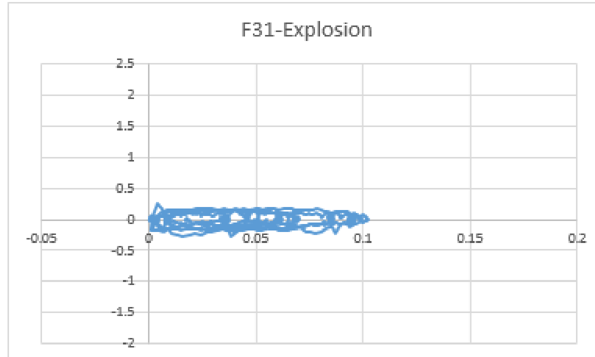
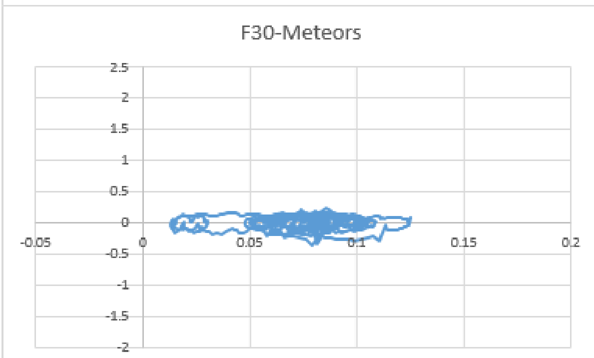
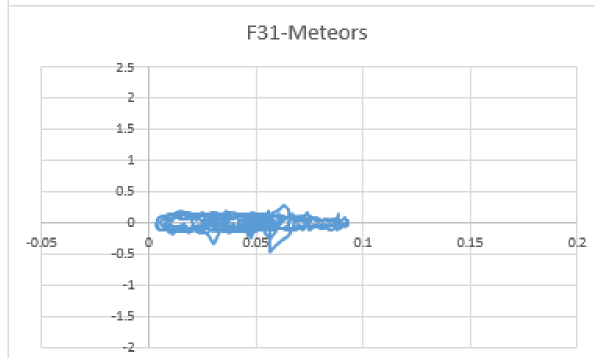
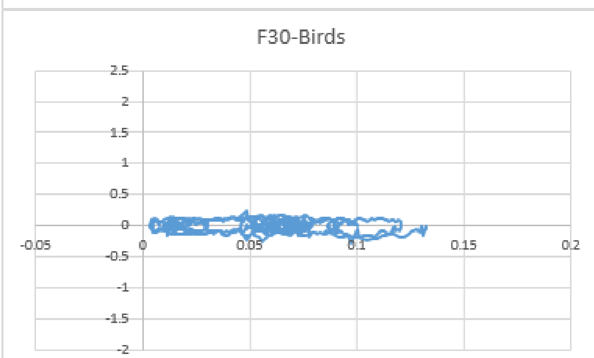
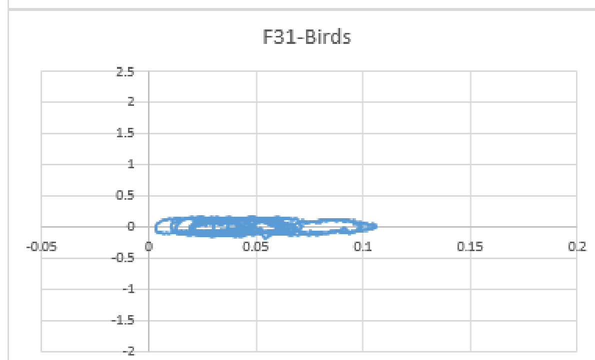
-0.5
-1
-1.5
-2
-0.05
0
0.05
0.1
0.15
0.2

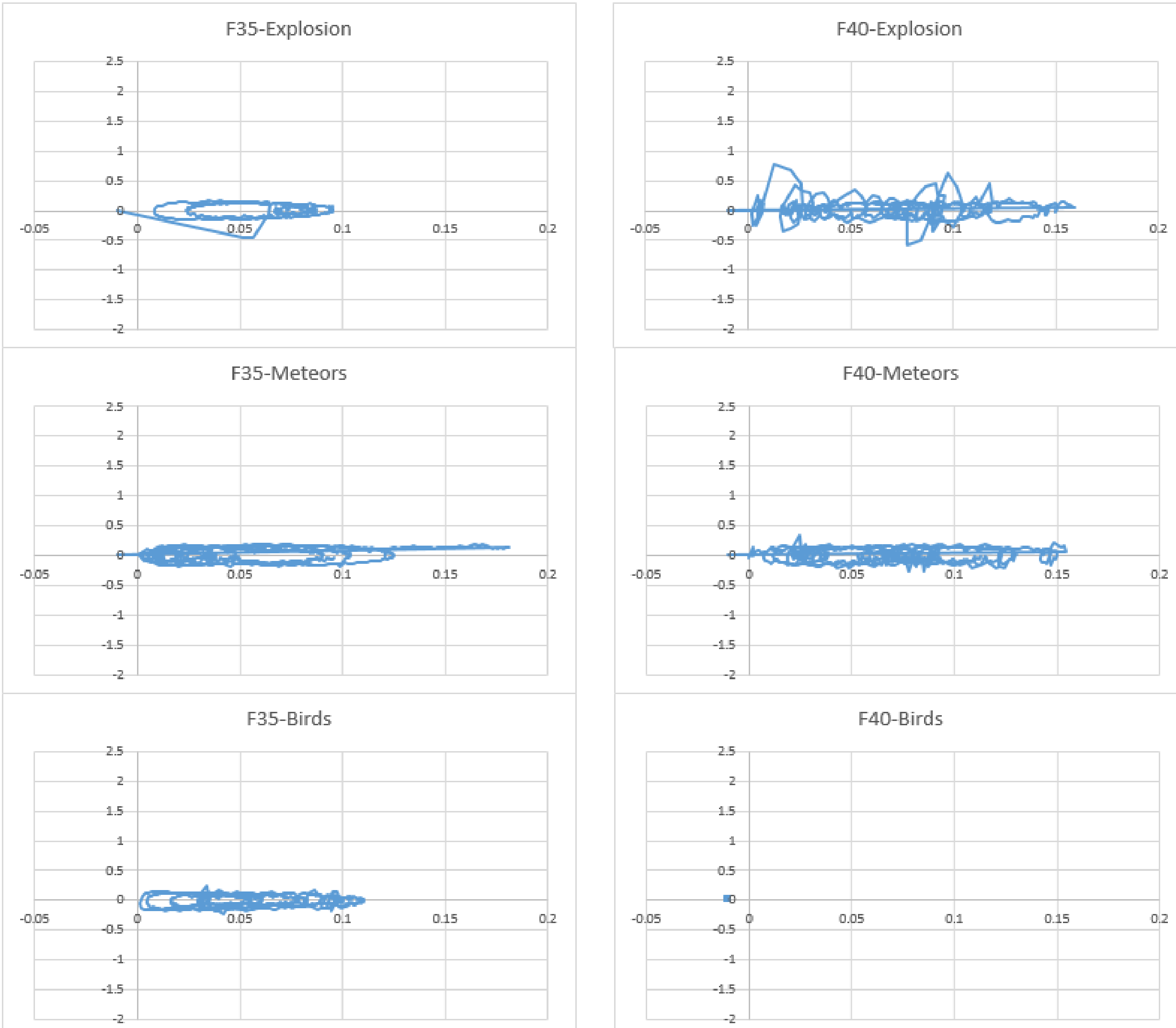

F31-Explosion
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-0.05
0
0.05
0.1
0.15
0.2

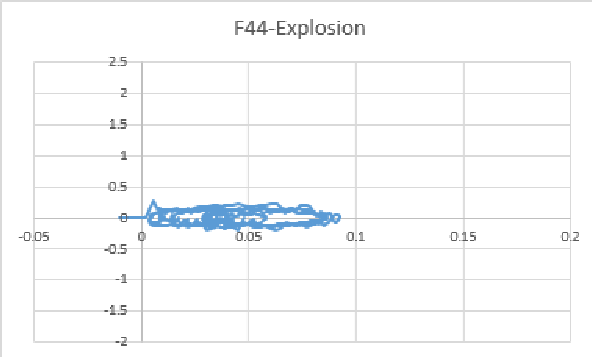

F30-Meteors
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-0.05
0
0.05
0.1
0.15
0.2

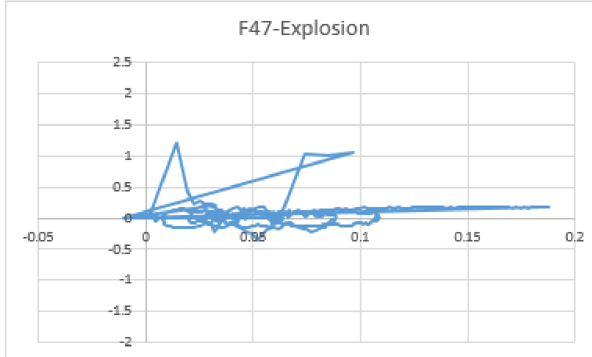

F31-Meteors
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-0.05
0
0.05
0.1
0.15
0.2

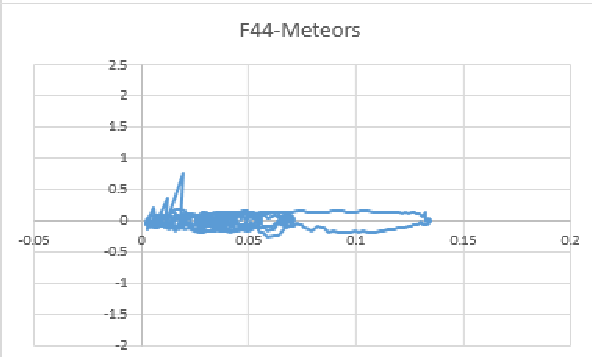

F30-Birds
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-0.05
0
0.05
0.1
0.15
0.2

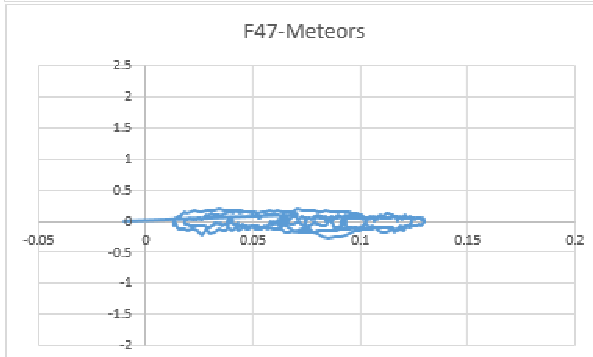

F31-Birds
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-0.05
0
0.05
0.1
0.15
0.2

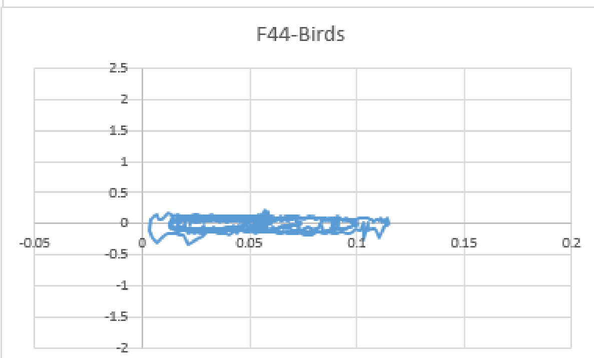

F35-Explosion
F40-Explosion
F35-Meteors
F40-Meteors
F35-Birds
F40-Birds
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-0.05
0
0.05
0.1
0.15
0.2

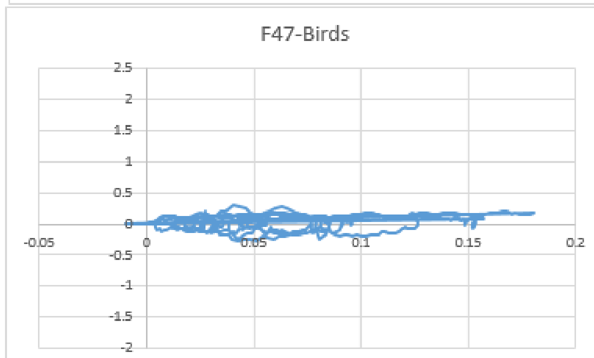

F44-Explosion
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-0.05
0
0.05
0.1
0.15
0.2

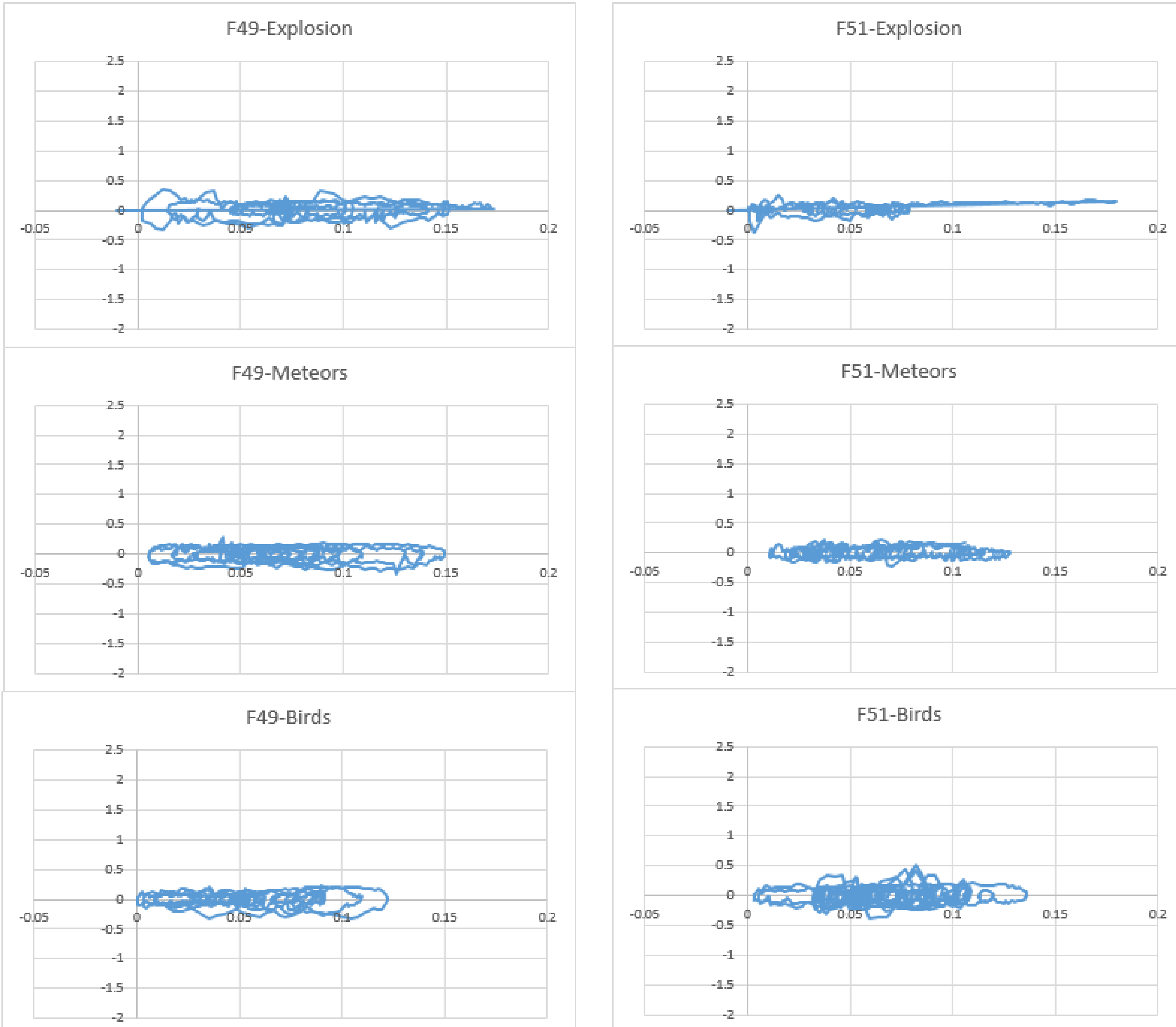

F47-Explosion
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-0.05
0
0.05
0.1
0.15
0.2

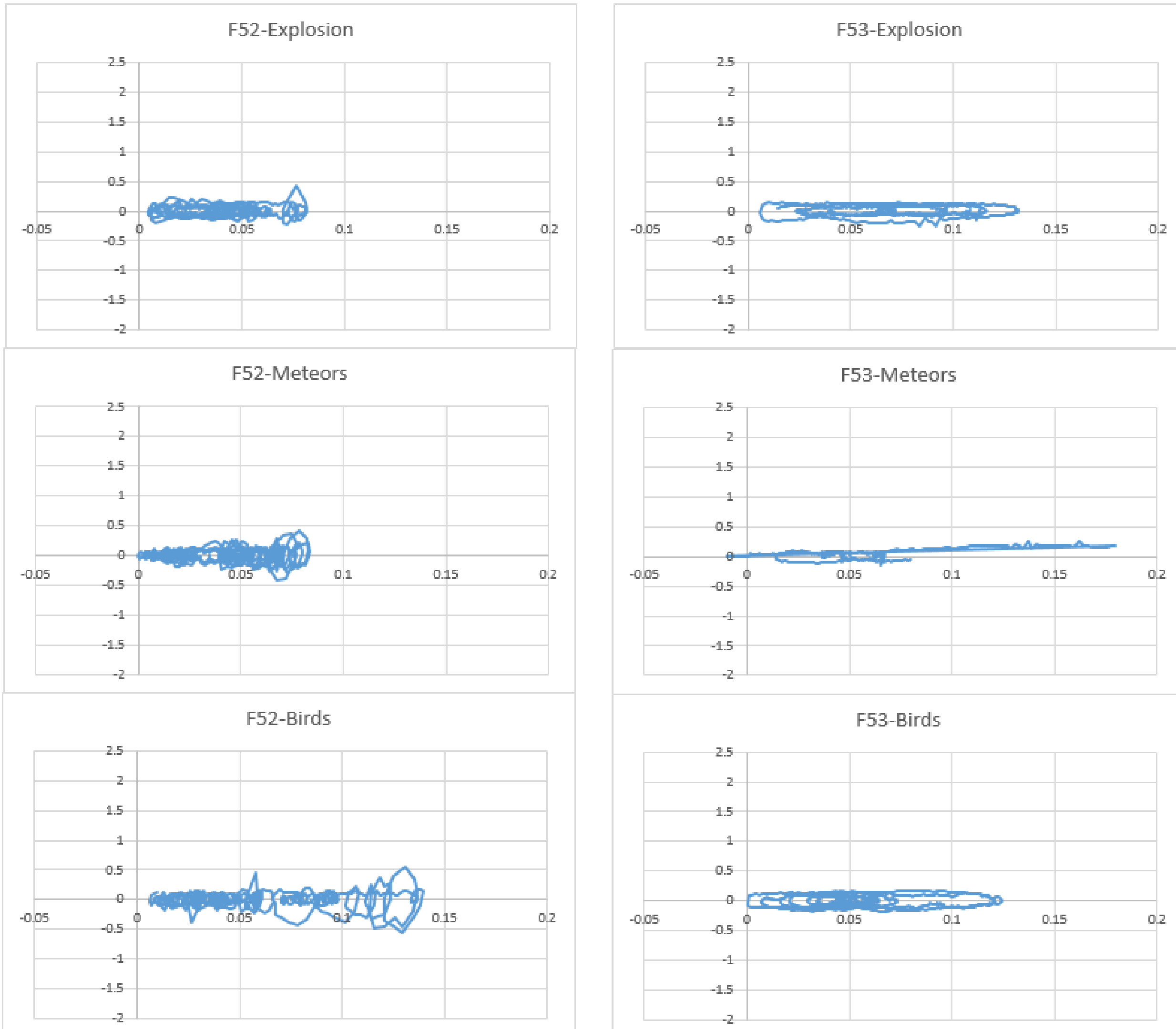

F44-Meteors
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-0.05
0
0.05
0.1
0.15
0.2

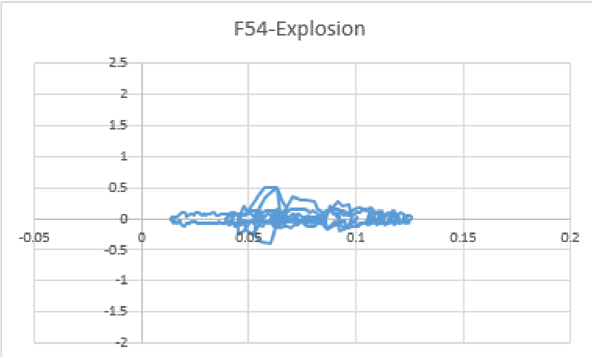

F47-Meteors
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-0.05
0
0.05
0.1
0.15
0.2

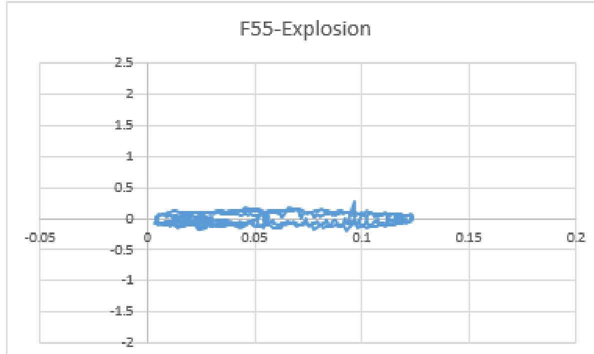

F44-Birds
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-0.05
0
0.05
0.1
0.15
0.2

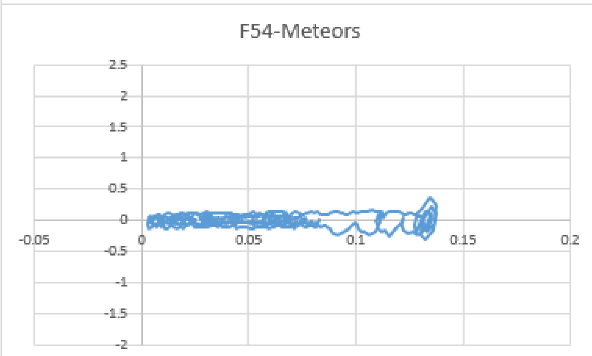

F47-Birds
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-0.05
0
0.05
0.1
0.15
0.2

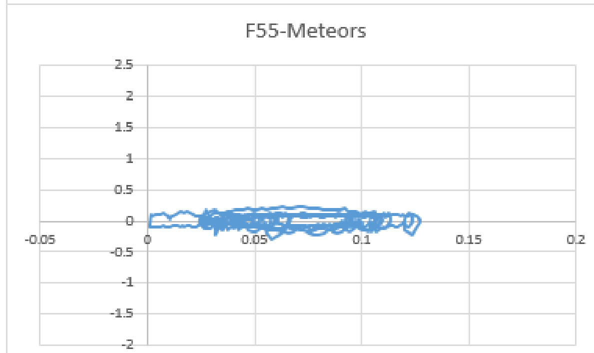

F49-Explosion
F51-Explosion
F49-Meteors
F51-Meteors
F49-Birds
F51-Birds
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-0.05
0
0.05
0.1
0.15
0.2

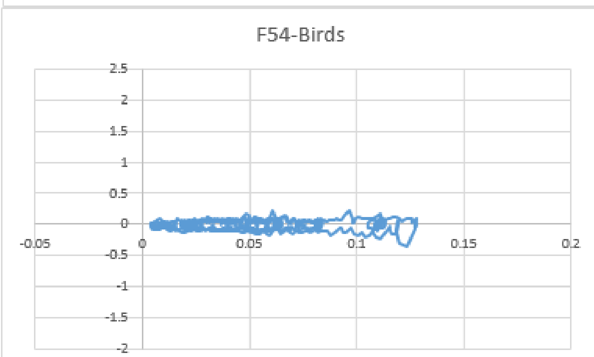

F52-Explosion
F53-Explosion
F52-Meteors
F53-Meteors
F52-Birds
F53-Birds
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-0.05
0
0.05
0.1
0.15
0.2

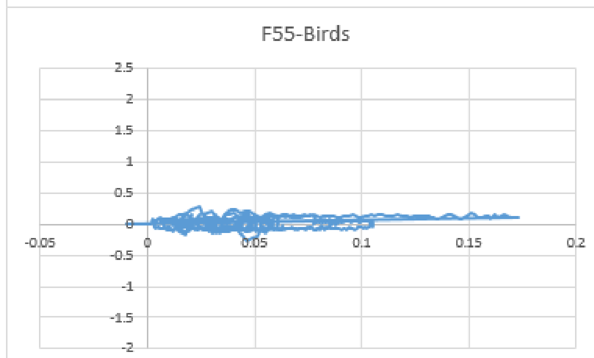

F54-Explosion
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-0.05
0
0.05
0.1
0.15
0.2

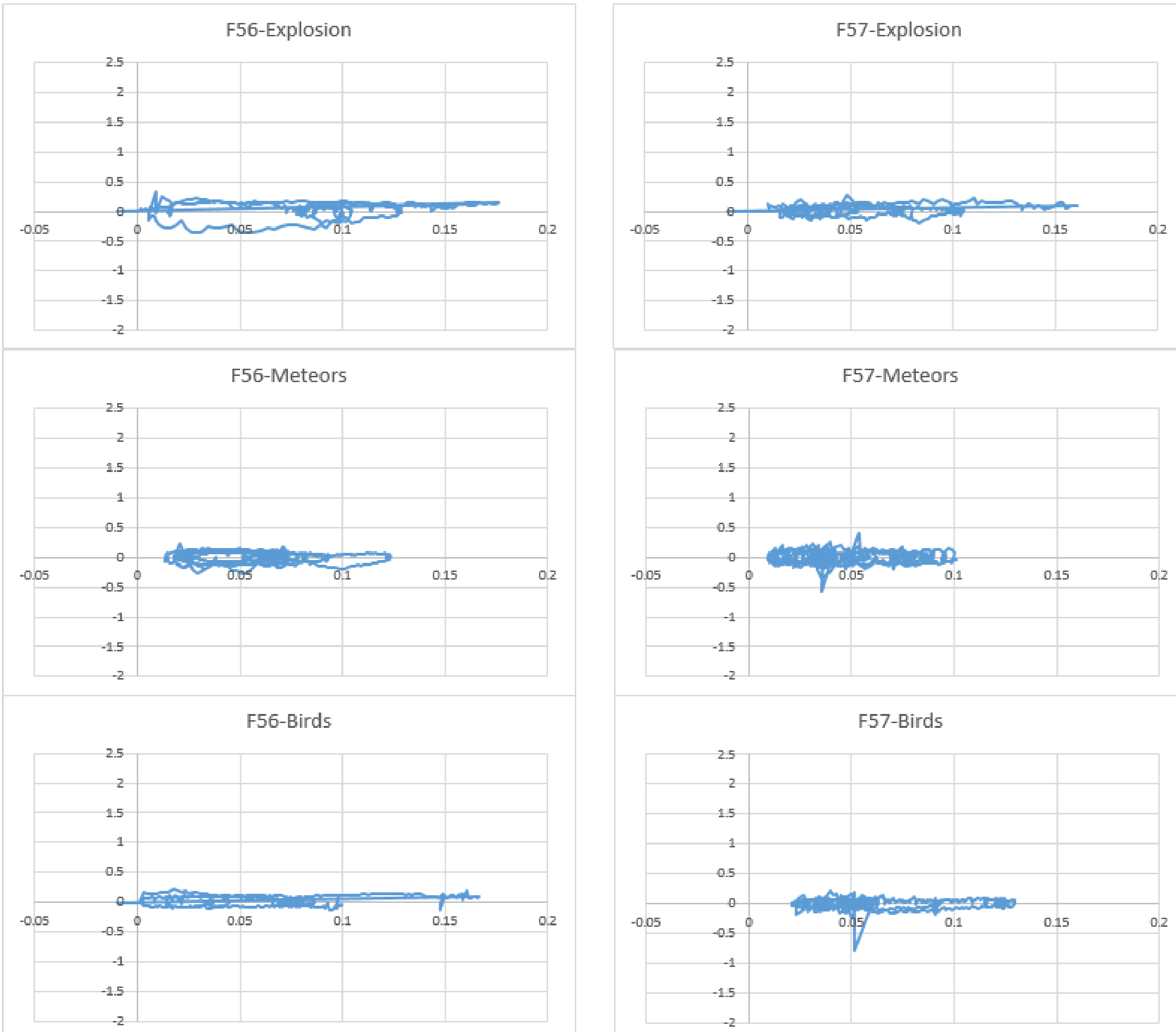

F55-Explosion
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-0.05
0
0.05
0.1
0.15
0.2

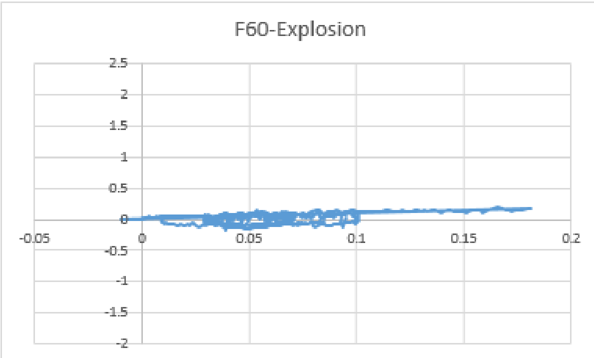

F54-Meteors
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-0.05
0
0.05
0.1
0.15
0.2


F55-Meteors
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-0.05
0
0.05
0.1
0.15
0.2


F54-Birds
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-0.05
0
0.05
0.1
0.15
0.2


F55-Birds
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-0.05
0
0.05
0.1
0.15
0.2


F56-Explosion
F57-Explosion
F56-Meteors
F57-Meteors
F56-Birds
F57-Birds
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-0.05
0
0.05
0.1
0.15
0.2


F60-Explosion
2.5
2
1.5
1
0.5
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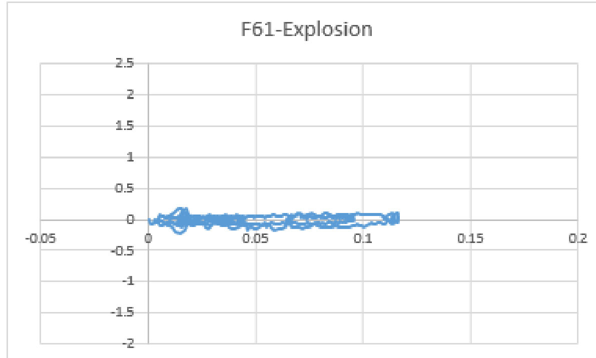
-0.5
-1
-1.5
-2
-0.05
0
0.05
0.1
0.15
0.2


F61-Explosion
2.5
2
1.5
1
0.5
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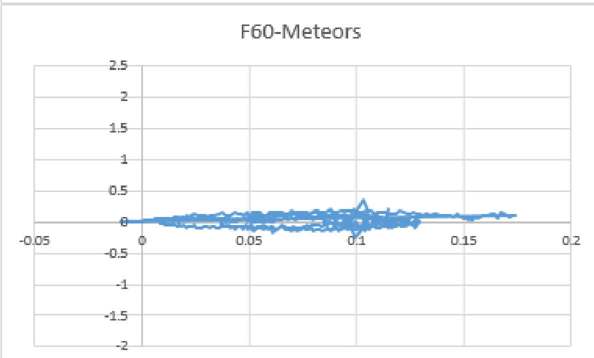
-0.5
-1
-1.5
-2
-0.05
0
0.05
0.1
0.15
0.2


F60-Meteors
2.5
2
1.5
1
0.5
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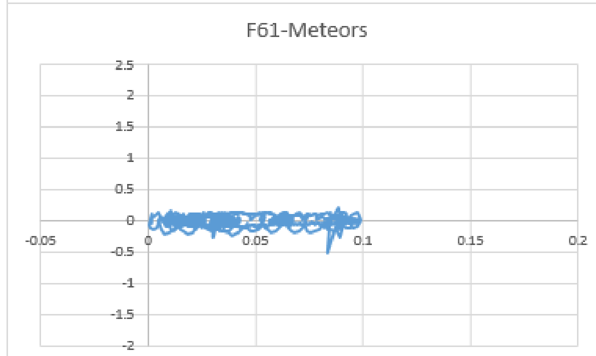
-0.5
-1
-1.5
-2
-0.05
0
0.05
0.1
0.15
0.2


F61-Meteors
2.5
2
1.5
1
0.5
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-0.5
-1
-1.5
-2
-0.05
0
0.05
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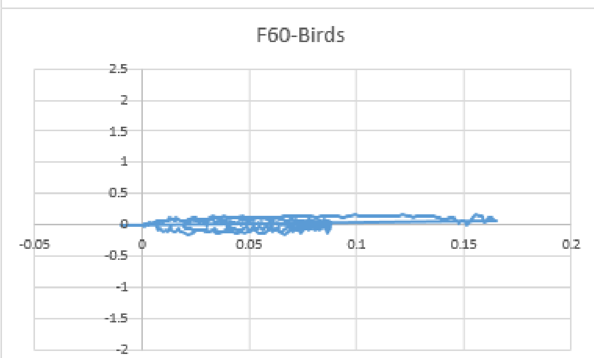
0.2


F60-Birds
2.5
2
1.5
1
0.5
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-0.5
-1
-1.5
-2
-0.05
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0.05
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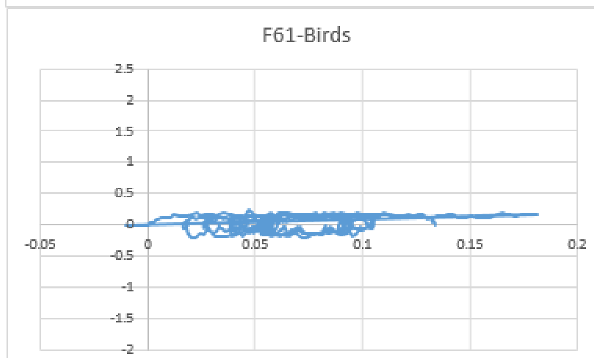
0.2


F61-Birds
2.5
2
1.5
1
0.5
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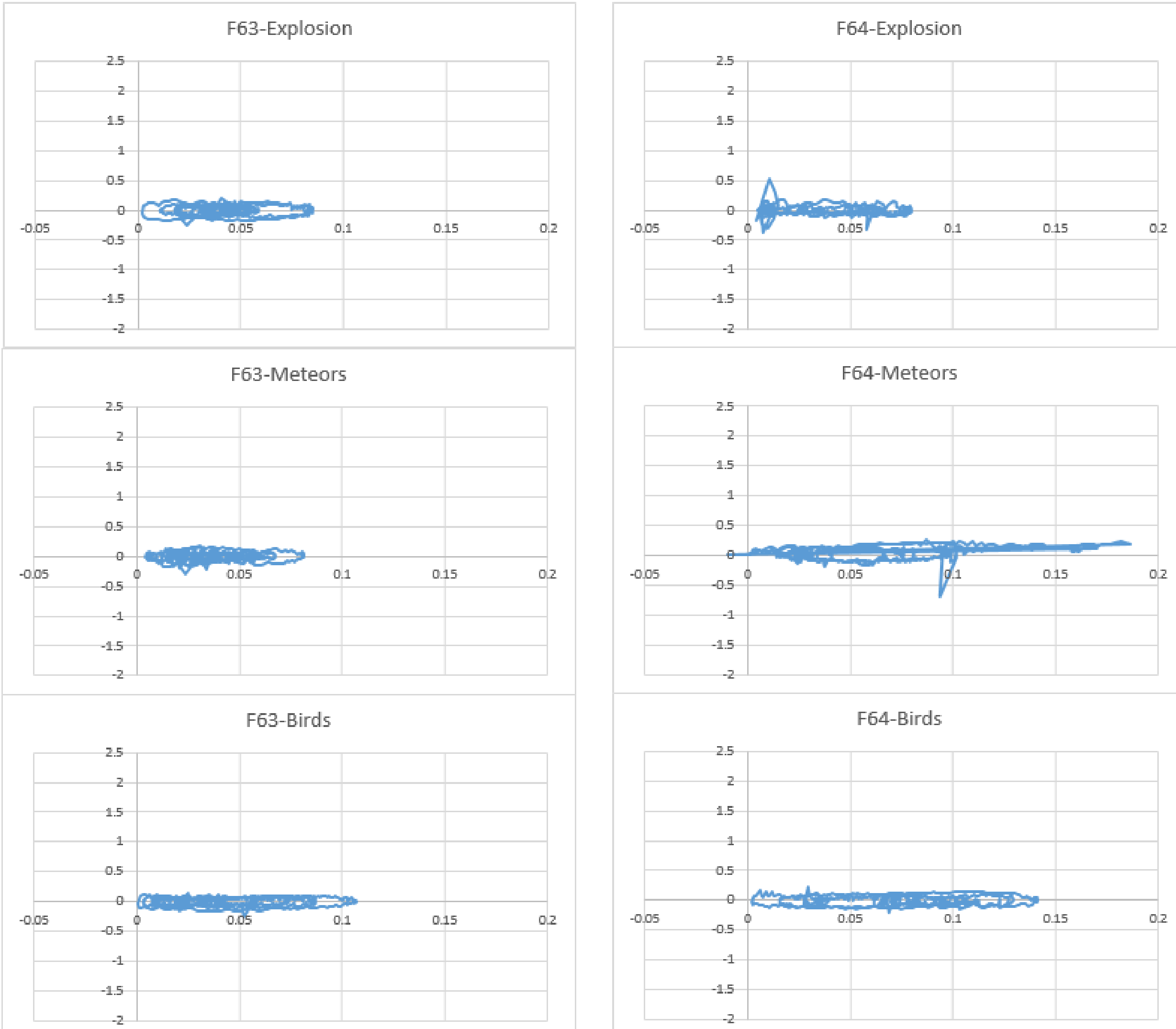
-0.5
-1
-1.5
-2
-0.05
0
0.05
0.1
0.15
0.2


F63-Explosion
2.5
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1.5
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0.5
0
-0.5
-1
-1.5
-2
-0.05
0
0.05
0.1
0.15
0.2
F64-Explosion
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-0.05
0
0.05
0.1
0.15
0.2
F63-Meteors
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-0.05
0
0.05
0.1
0.15
0.2
F64-Meteors
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-0.05
0
0.05
0.1
0.15
0.2
F63-Birds
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-0.05
0
0.05
0.1
0.15
0.2
F64-Birds
2.5
2
1.5
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0.5
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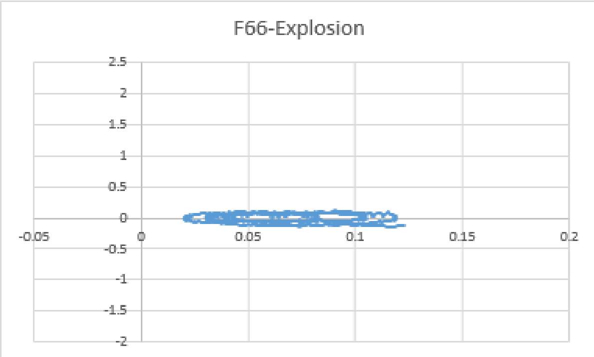
-0.5
-1
-1.5
-2
-0.05
0
0.05
0.1
0.15
0.2


F66-Explosion
2.5
2
1.5
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0.5
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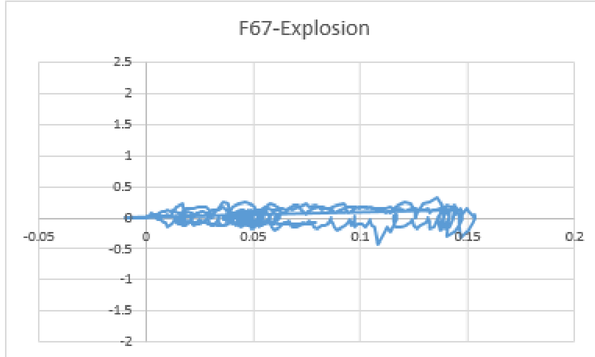
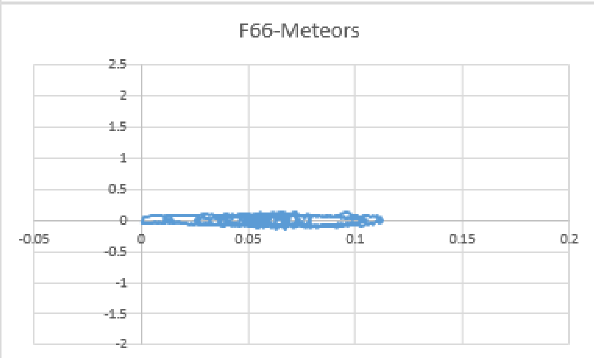
-0.5
-1
-1.5
-2
-0.05
0
0.05
0.1
0.15
0.2


F67-Explosion
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-0.05
0
0.05
0.1
0.15
0.2


F66-Meteors
2.5
2
1.5
1
0.5
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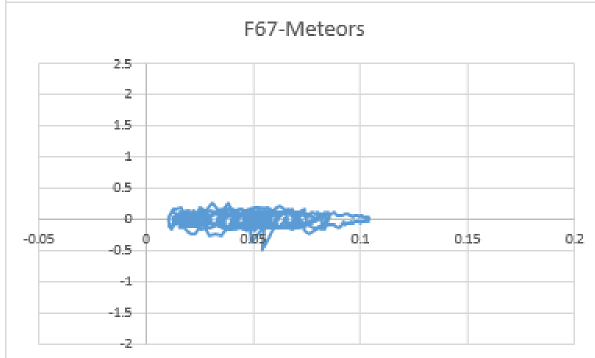
-0.5
-1
-1.5
-2
-0.05
0
0.05
0.1
0.15
0.2


F67-Meteors
2.5
2
1.5
1
0.5
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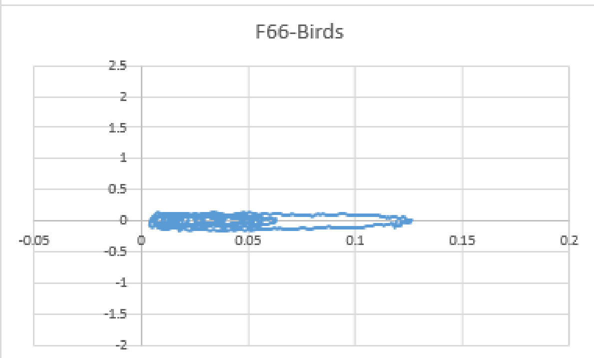
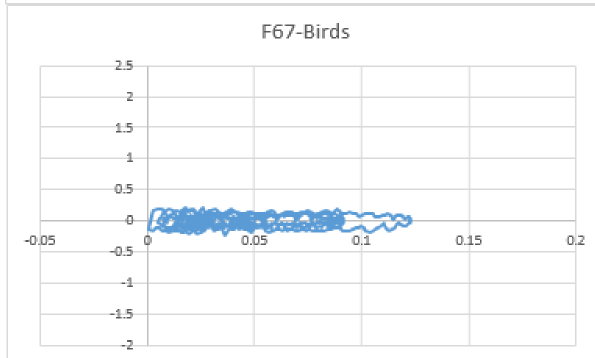
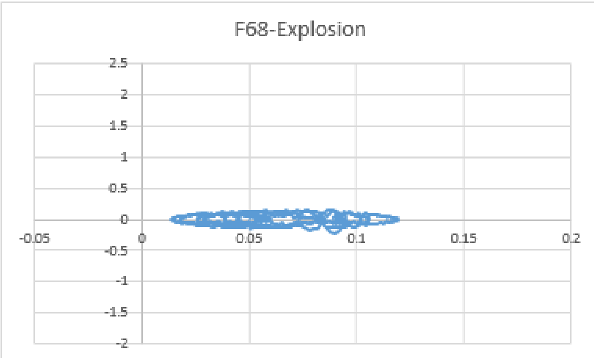
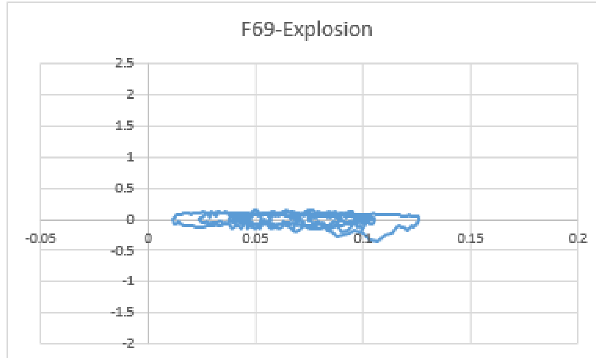
-0.5
-1
-1.5
-2
-0.05
0
0.05
0.1
0.15
0.2


F66-Birds
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-0.05
0
0.05
0.1
0.15
0.2


F67-Birds
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-0.05
0
0.05
0.1
0.15
0.2


F68-Explosion
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-0.05
0
0.05
0.1
0.15
0.2


F69-Explosion
2.5
2
1.5
1
0.5
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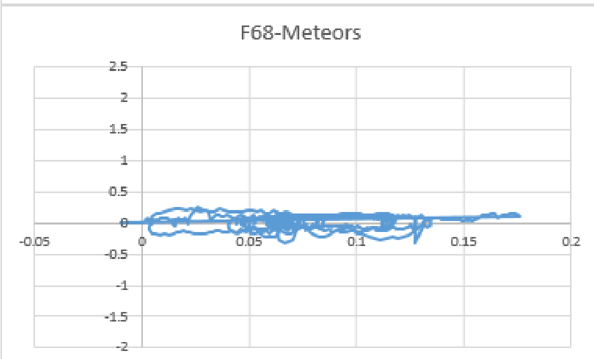
-0.5
-1
-1.5
-2
-0.05
0
0.05
0.1
0.15
0.2


F68-Meteors
2.5
2
1.5
1
0.5
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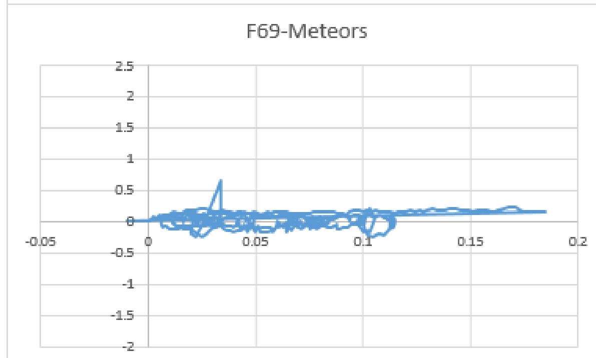
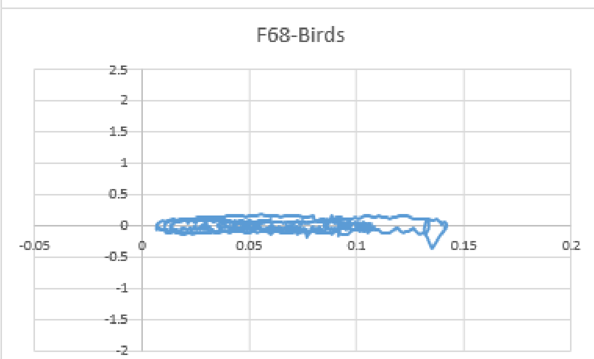
-0.5
-1
-1.5
-2
-0.05
0
0.05
0.1
0.15
0.2


F69-Meteors
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-0.05
0
0.05
0.1
0.15
0.2


F68-Birds
2.5
2
1.5
1
0.5
0
-0.5
-1
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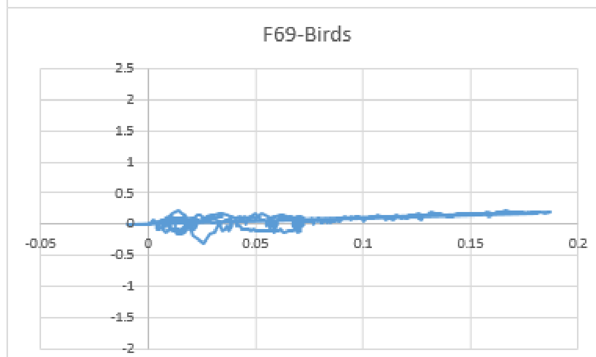
F69-Birds
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BIOGRAPHICAL SKETCH

Daniel Gracia De Luna was born in Monterrey, Nuevo Leon in 1989. Daniel earned his B.S. as a Mechatronic Engineer with Concentration in Automotive Engineering in the Instituto Tecnologico y de Estudios Superiores de Monterrey in 2015. During these studies, he completed a study abroad in 2013 to Germany in Hochschule Esslingen, University of Applied Sciences. Daniel worked at Navistar (International Trucks) from 2015 to 2017 as a New Product Development Engineer Jr. in the Power Train Team, working directly with the Engines. In 2017 he started his M.S. in Engineering Management in the University of Texas Rio Grande Valley, and worked as a Teaching Assistant from February 2018 to May 2019. And in August 2019 Daniel earned a Master of Science degree in Engineering Management in the University of Texas Rio Grande Valley. To contact Daniel Gracia De Luna, it is possible by email on dgdl5236@gmail.com.