DESIGNING BETTER EXERGAMES: APPLICATION OF FLOW CONCEPTS AND THE FITT PRINCIPLE TO FULL BODY EXERTION VIDEO GAMES AND FLEXIBLE CHALLENGE SYSTEMS

by

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ABSTRACT

ANDREA NICKEL Designing better exergames: application of flow concepts and the FITT principle to full body exertion video games and flexible challenge systems. (Under the direction of DR. TIFFANY BARNES)

Exercise video games have a recognized potential for widespread use as tools for effective exercise. Current exergames do not consistently strike a successful balance between the "fun gameplay" and "effective exercise" aspects of the ideal exergame. Our research into the design of better exergames applies existing gameflow research and established exercise guidelines, such as those published by the American College of Sports Medicine, to a collection of four custom exergames: Astrojumper, Washboard, Sweet Harvest and Legerdemain implement full-body motion mechanics that support different types of exercise, and vary in intended duration of play, game complexity, and level of physical challenge. Each game also implements a difficulty adjustment system that detects player performance from in-game data and dynamically adjusts game difficulty, in order to balance between a player's fitness level and the physical challenge presented by the game. We have evaluated the games produced by our design approach through a series of user studies on players' physiological and psychological responses to gameplay, finding that balance between challenge types (cognitive or physical) is an important consideration along with challenge-skill balance, and further, that game mechanics able to support creativity of movement are an effective means of bridging between gameplay and exercise in order to improve the player experience.

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CHAPTER 1: INTRODUCTION TO EXERGAME RESEARCH

Current, commercially available video game platforms and peripheral hardware have increased developers' capability to design games and applications that use players' physical movements as input; turning the player's own body into a game controller and using gestures or other physical actions as game mechanics. The Nintendo Wii console (Nintendo, 2006) with the Wiimote controller and attachments, the PlayStation Move (Sony, 2009), and the Microsoft Kinect (Microsoft, 2010) each utilize a variety of technologies that allow gesture detection and motion sensing. These and other devices have allowed the traditionally sedentary pastime of video gaming to evolve in new directions, and become an activity that can incorporate and promote physical motion and exercise. As these technologies have become more widely available, games designed to provide exercise, called exergames or active video games, have become the focus of a growing, diverse research area.

The ideal exergame is both fun and effective. Gameplay should be an enjoyable experience that immerses players in an activity, encouraging them to complete and replay games. The gameplay should also involve physical activity sufficient to contribute towards improving or maintaining some aspect of fitness. Balancing the "work" and "play" aspects of exergames has been shown to be a challenge, and is the area of contribution for this exergame design research. Through study and application of existing exergame design theory, we have gained new insights into the development of exergames that are both motivating and effective, and into the exergame user experience, that may be used by developers and researchers to develop more fun, effective exergames. In regards to the aspect of "play," or designing for an enjoyable, motivating game experience, we have examined existing concepts of flow and game balance and how they work when applied to different types of exergames. For the aspect of "work" we have investigated ways to increase the effectiveness of the exercise supported through gameplay. We define effective exercise as activity that, when performed on a regular basis, leads to health and fitness benefits. Our approach here has included the development of a set of exergames and exergame prototypes that demonstrate how to support different types of exercise. Additionally, we have experimented with systems that use player performance data to dynamically adjust in-game difficulty settings to provide players at different levels of fitness with an effective physical challenge. Also, the intersection between work and play has been considered in our design research, as we have found that these aspects need not always be approached separately.

In the following sections we will briefly describe the health-related motivations behind exergame research, and summarize the principal research challenges facing the field. We will then situate the present work in relation to the principal challenges, and outline its contributions.

1.1 Motivation

A primary motivation behind research and commercial interests in exergame development is the widespread recognition that recent obesity trends pose a serious health concern. One-third of children and adolescents (ages 2-19) are overweight or obese (Matthews et al., 2011), as are over two-thirds of U.S. adults (ages 20 and older) (Flegal et al., 2010). The problem does not just exist in the U.S. According to the World Health Organization, worldwide obesity has more than doubled since 1980 (WHO, 2012). Obesity leads to a number of related health problems, including cardiovascular disease, hypertension, diabetes, and several psychological disorders such as depression (Warburton et al., 2007). These health problems can be alleviated by the adoption of regular physical activity. However, many Americans do not reach the minimum exercise recommendations for health benefits. About 43% of adults are inactive; and worldwide, about one-third of adults and four-fifths of adolescents do not reach recommended physical activity levels (Hallal, 2012).

1.2 Suitability of Exergames to Promote Physical Activity

Exergames are designed to elicit physical activity and energy expenditure in players. They have been implemented using the Wii or Wii Fit balance board, the Move or the Kinect; dance pads, smartphones, traditional exercise equipment such as treadmills with attached sensors or gaming devices, and many other custom platforms. With the goal of encouraging increased physical activity and related health benefits, these applications attempt to leverage the characteristics or elements of games that make them entertaining and intrinsically motivating to transform traditional exercise into an activity that is more engaging than a typical, repetitive exercise routine (Ahn et al., 2009). Video games may be particularly well suited for this purpose. The Entertainment Software Association's 2011 report on the sales, demographic and usage data of video games states that 72% of households in the U.S. play computer or video games (ESA 2011), while the 2012 report states that the average household owns at least one dedicated game console, PC or smartphone and that game players include people of all ages, genders and ethnic groups (ESA, 2012). Also, given the specific motivational and educational needs of today's youth, technology-based solutions may have more success than traditional methods in impacting their health behaviors (Casazza et al., 2006; Papastergiou, 2009; Silverstone & Teatum, 2011). This suggests that video games intended for exercise are able to reach a wide audience, and given their accessibility to people across demographic groups, exergames have significant potential to encourage many to include more physical activity in their daily lives.

The flexibility of technology and application development also means that exergames can go beyond the goal of making exercise fun. Video games can contribute to health education, the acquisition of motor skills or physical rehabilitation (see Kafri et al., 2011; Vuong et al., 2011; and Weybright et al., 2010 for a small sample). Exergames can also result in psychological and social benefits, improving moods or facilitating the development of social networks and decreasing loneliness (Höysniemi, 2006; Mueller et al., 2003, 2008; Rosenberg et al., 2010; Siegel et al., 2009); and additional benefits to specific populations, such as children with autism, have also been observed (Nicholson, 2008). Exergames can present a physical challenge that can be customized to individual players' specific needs or desires, and to individual fitness levels. They can also greatly increase players' awareness of their physical activity habits and fitness levels, which is an important component of the adoption of behavioral changes (McLean et al., 2003). Exergame systems can provide players with feedback on their performance and progress, and help develop individualized short- and long-term fitness goals.

1.3 Overview of the Principal Research Challenges in Exergaming

The above paragraphs describe the remarkable potential exergames have to be tools for health and fitness awareness and improvement. As exercise game research has advanced, several primary design challenges have become evident. These issues exist beyond those design challenges presented by traditional or other serious games, and may be placed in the categories of 1) motivating repeat play, 2) attractiveness-effectiveness balance, 3) social interaction, 4) platform, and 5) safety. We will briefly discuss each of these and identify the areas of contribution for this research.

1.3.1 Motivating Repeat Play

Exercise leads to health benefits only if performed regularly, so an exergame that aims to provide health benefits must consider game replay value and other factors that motivate long-term use or behavioral changes. Design challenges lie in deciding which game elements will be the best contributors toward these goals and how they may be implemented. Researchers have previously focused on narrow demographic categories to determine the most successful motivating factors, as different populations are often motivated differently. For example, Arteaga et al. (2010) focused specifically on adolescents, and Toscos et al. (2008) on teenage girls. Other research that discusses exergame design theory includes descriptions of game elements that act as motivating factors (Campbell et al., 2008; Consolvo et al., 2006; Yim & Graham, 2007).

1.3.2 Attractiveness-Effectiveness Balance

A second issue is the balance between “work” and “play.” An exergame must be engaging in terms of the challenges it presents and the skills needed by the player to overcome those challenges, but it also must be able to provide fitness activities of an appropriate intensity, as Sinclair et al. (2007) describe in their dual-flow model of attractiveness and effectiveness: respectively, the psychological aspect of gameplay and the physiological aspect of physical activity. Many existing games, both commercial and academic, have some difficulty achieving this balance (Berkovsky et al., 2010; Hämäläinen et al., 2005; Luke et al., 2005; Smith, 2005). As will be further explained in the following literature review, many current exergames focus on either more traditional workout programs supported by gaming technology, or on gameplay that uses gesture-based controls as a novel form of interaction but involves insufficient physical movement to help players maintain or improve health or fitness.

1.3.3 Social Interaction

Social interaction is recognized as an important motivational aspect of video games, and social support for exercise is also important (Ahn et al., 2009; Mueller et al,. 2003, 2008, 2010). There are a number of mobile exergames or activity tracking applications that incorporate social elements like group cooperation or competition and sharing of progress information (Anderson et al., 2007; Barkhuus et al., 2005; Bell et al., 2006; Lin et al., 2006; Stanley et al., 2008; Tiensyrja et al., 2010; Vogiazou et al., 2007). However, the inclusion of social game elements may lead to other issues: people may not know how to motivate others (Toscos et al., 2008), people who do not participate may de-motivate others (Lin et al., 2006), or people at different physical ability levels may have difficulty playing together, although some work has examined the possibility of using player heart rate to control game difficulty and narrow the ability gap between players in a social game (Koivisto et al., 2011; Stach, 2009; Wylie & Coulton, 2009).

1.3.4 Platform

The selection of an exergame platform has an impact on what the game may accomplish; for example, what type of exercise may be supported. An adapted treadmill or exercise bike may be able to provide very effective physical activity, but it may limit options for game interactivity (Mokka et al., 2003). Mobile iPhone games may have difficulty promoting sufficient physical activity but provide more extensive options for social interaction and for fitting activity into everyday routines. Additional considerations may arise for mobile games, including the possible need to design a game that frees a player's attention from visuals on a display as they engage in the game while simultaneously navigating an outdoor environment (Hendrix et al., 2008).

1.3.5 Safety

Finally, player safety should always be considered. The involvement of health professionals in exergame design may ensure that a game's physical requirements will not cause a player physical damage such as the minor injuries occasionally sustained by Dance Dance Revolution players (Höysniemi, 2006). Games that educate and guide players' exercise routines, as does the interval training application developed by Myung-kyung et al. (2009), need to be based on correct exercise guidelines.

1.4 Contributions of the Present Work

The above descriptions are of broad research challenge areas, and each encompasses multiple opportunities for future exploration. For our own work, we have focused on the issue of attractiveness-effectiveness balance and the following research questions:

Attractiveness:

- What additional insights into designing for exergame usability or attractiveness may be gained through the study of existing design theory, and its application to exergames with different exercise goals? (Section 1.4.1)

Effectiveness:

- How may established guidelines for exercise be better incorporated into exergame design, in order to improve the effectiveness of exercise provided through play? (Section 1.4.3)

Attractiveness-Effectiveness Balance:

- How may we implement game challenge adjustment systems that dynamically evaluate player performance and appropriately modify game difficulty? (Section 1.4.2)
- What balance of exertion and play is most successful from a player experience perspective? (Section 1.4.1)

1.4.1 Designing for a Better Player Experience

Literature that discusses the design of successful player experiences in traditional video games often mentions the concept of "flow" as an optimal play state, attained by allowing a player to constantly make interesting strategic decisions regarding game challenges and thereby exercise their skills within the game, and rewarding them for doing so (Brathwaite & Schreiber, 2009). Challenges can be seen to have two sides: the amount of cognitive effort required to overcome them and the pace at which the game presents them; the appropriate balance between these is dependent on player skill (De Castell & Jenson, 2007). Other theories have been utilized, for example, Przybylski et al.

(2010) apply self-determination theory (Deci & Ryan, 2000) to their study of video game engagement, but the stated need to balance between game challenge and player skill, and to provide continual feedback as players exercise their skill, remains constant.

Exergames add another dimension to the problem of balancing challenge and skill. While it is still necessary to consider the cognitive demands of challenges presented by the game and how players' development of game-playing skills and strategies will be enabled, exergame designers must additionally consider the physical demands of the game and what forms or degrees of exertion players will engage in to meet them. Sinclair et al. (2007) touch on this problem in their discussion of exergame attractiveness and effectiveness; respectively, the cognitive and physical dimensions of exergame-play. Of exergames' principle research challenges, attractiveness-effectiveness balance is perhaps one of the most important: as stated, an ideal exergame provides both an engaging experience and an effective workout. An exergame's success in both areas directly affects the other important challenge of motivating repeated play, as it seems reasonable to believe that a game which is neither fun nor able to assist with a player's exercise goals will not be played often. When considering players' psychological responses to an exergame experience, and how best to combine gaming and exercise experiences, there are several issues that help explain why attractiveness-effectiveness balance remains a challenge.

It has been noted that the design of games that take advantage of the "body-as-controller" capabilities of technology such as the Microsoft Kinect remains something of an unexplored space. Traditional computer and console game controllers have existed much longer in comparison, and designers have a thorough understanding of how to use them. However, little research has focused on how body movements can be used to support gameplay in a form that goes beyond the substitution of gestures for button presses (de Kort & Ijsselsteijn, 2008). Commercial games that use physical movement or exertion mechanics receive lower-scored reviews than games that use traditional controllers, even if it is the same title (Graft, 2009). The lack of experience designers have with motion controls is one reason why exergame attractiveness can be difficult to achieve, and for an exergame, the need for the motion controls to also constitute effective exercise adds an additional layer to the design problem.

Also discussed in the literature is the lack of both theoretical and empirical understanding of how body movement as a method of interaction affects the user experience in a video game context (de Kort and Ijsselsteijn, 2008; Hummels et al., 2007; Moen, 2006). Hummels et al. (2007) discuss the differences in designing with a focus on cognitive as opposed to physical skills, and Moen's (2006) dissertation examined properties of human movement as a means of interacting with technology through the study of people engaging in dance-based movement and interactions.

Our research helps to address both of the above knowledge gaps. As part of our exergame design work we have experimented with new game mechanics, working to implement full-body physical interactions that are an integral part of the game experience, that feel natural for players and are also able to support exertion at a sufficient intensity for effective exercise. The games we have developed each use different types of gameplay and physical interactions in support of different forms of exertion. User studies conducted to evaluate each game contribute data toward the understanding of how player experiences vary across these different exergames. The insights into motion-controlled and exertion game design that we have gained will be discussed throughout this paper.

1.4.2 Dynamic Game Difficulty Adjustment Systems

It is difficult to construct “one-size-fits-all” exergame systems. Variety in players’ abilities, fitness levels, goals or motivations, training requirements and preferences give rise to the need for an amount of customization not present to the same extent among traditional games. Some existing work addresses this issue by designing games for specific audiences (Arteaga et al., 2010; Toscos et al., 2008), and other work introduces authoring systems so that games or game prototypes may be designed by members of the different audiences themselves or by health experts working with them (Göbel et al., 2010; Payton et al., 2011).

As a means of exergame individualization, the present work will concentrate on implementations of dynamic difficulty adjustment systems. The purpose of these systems is to allow our exergames to detect player performance or ability and adjust game difficulty while the game is being played, in order to provide an appropriate (neither too easy nor too difficult) level of challenge for the player. Also, these systems provide a means of sustaining challenge, giving exergames the ability to continue challenging players through repeated play sessions, even as players’ skills with the game and physical fitness levels improve. The ability to adapt exergame challenges to different players’ needs is an important supporting factor of long-term player motivation: players, depending on their personal goals, may not be motivated to continue playing a game that is too easy and does not contribute toward their health and exercise objectives. They will also not be motivated to play a game that is too difficult and potentially frustrating. In order to sustain player interest, it is necessary to find a good balance between player skills and the challenges offered by a game: this can be tied in directly with the previous mention of challenge-skill balance as an important factor in a "flow" experience, and potentially addresses the need to balance both cognitive and physical challenges and skills.

Furthermore, it is our goal to explore difficulty adjustment systems that do not require extra equipment that must be used or worn during play. All of the work found and included in the reviewed literature that deals with dynamic difficulty adjustment utilizes heart rate monitor input, through wearable HR monitors or less common game equipment like game-enabled treadmills or the GameBike (Kiili & Merilampi, 2010; Koivisto et al., 2011; Masuko & Hoshino, 2006; Nenonen et al., 2007; Sinclair et al., 2010; Stach et al., 2009; Wylie & Coulton, 2009; Zhang et al., 2011). Instead of following suit, we aim to use more common platforms (i.e. the Microsoft Kinect) and not increase the number of devices that must be used to play and monitor performance, simplifying the exergame platform from the users' point of view. We demonstrate that sufficient performance and usage data may be collected by the game to support dynamic difficulty adjustment that results in appropriate challenge for players with different physical abilities. We are also, through our multiple games and game prototypes, able to explore details of difficulty adjustment systems that may differ depending on the type of exercise being performed.

1.4.3 Incorporating Exercise Effectiveness Guidelines in Exergame Design

Our work approaches exercise from a gaming perspective in that we believe movement can be fun in and of itself, and an opportunity for creativity, and as such can provide new, successful mechanics for improved exertion video games. However, we also recognize that from a health perspective there are guidelines defining effective exercise, or exercise that is able to help individuals maintain or improve fitness. We have used these guidelines, described briefly below, as an important component in our exergame design process.

1.4.3.1 Applying the FITT Principle to Exergames

The FITT principle can be used to formulate exercise prescriptions using the characteristics of frequency, intensity, time and type. Frequency refers to how often a person exercises per week, intensity governs how energetically a person exercises (e.g. at light, moderate, or vigorous intensity), time simply refers to the duration of an exercise session, and type is that of the exercise being performed (e.g. aerobic, anaerobic, etc.) (Swain, 2005; Tancred & Tancred, 1996).

To address the effectiveness-related research question stated above, we built games to support the different elements of exercise routines outlined by the FITT principle, looking mainly at intensity and type. The element of frequency relates more closely to the question of player motivation, and thus falls outside the scope of this work, as described in section 1.6. We do take the element of time, or the duration of an exercise session, into consideration as we follow ACSM guidelines (Garber et al., 2011) for exercise; this is briefly discussed below. However, an intended contribution of this work lies in its demonstration of how exergames can be made that support different types of exercise, and how these games implement systems to dynamically adjust the level of challenge in order to encourage exertion at a sufficient intensity so as to aid in fitness improvement.

1.4.3.2 Exercise Intensity and Type

We will present games that focus individually on aerobic exercise, anaerobic exercise (core muscle development), and stretching or flexibility. We will also explore a game made up of a sequence of levels that incorporate a mix of aerobic and anaerobic exertion, taking into account the need for different exercise types in an effective fitness program. Our Sweet Harvest game is designed as a warm-up activity using stretching exercises and therefore is meant only for light exertion, but most of our games are designed to elicit moderate intensity exertion from players at a level that with repeated play would result in health benefits. Game intensity evaluation methods include measuring heart rate and energy expenditure; these are discussed further in section 3.2.1.

1.4.3.3 American College of Sports Medicine (ACSM) Guidelines for Exercise

The ACSM puts forth recommendations regarding exercise type and quantity needed to maintain or improve fitness. For example, it is suggested that adults engage in 30-60 minutes of moderate-intensity cardiorespiratory ("aerobic") exercise on at least five days per week, with a target of 150 minutes of exercise (or less for vigorous-intensity exertion). Daily exercise may be accumulated in bouts of at least 10 minutes each. Resistance and neuromotor training exercises should be done two to three days per week, and flexibility exercises should also be done at least 2-3 days per week with the greatest benefits occurring from daily training (ACSM, 2011).

The games we present here are designed to have flexible duration and to provide enough play time to fill at least the minimum duration defined by the ACSM guidelines (e.g. at least 10 minutes for aerobic exercise). We also take into account the warm-up and cool-down phases described by the ACSM (Whaley, 2005) that should surround the main exercise session, and we note the suggestion that a "dynamic, cardiorespiratory endurance exercise warm-up" is superior in some ways to flexibility exercises as a pre-workout activity (ACSM, 2011). In sections 4-8 of this paper, our individual games and their forms of adherence to the warm-up, workout, cool-down progression will be described.

1.5 Relating the Present Work to the Principal Research Challenges

The main research questions of the proposed work, regarding the investigation of attractiveness-effectiveness balance, application of exercise guidelines to exergame design and the implementation of dynamic difficulty adjustment systems, fit within the principal research categories of motivating repeat play and balancing attractiveness and effectiveness. The following describes how addressing these research questions will contribute to the broader issues named and also briefly discusses other ways in which the present work is influenced by these larger concerns.

1.5.1 Motivating Repeat Play

Studies of the psychological bases for player motivation, or specific game elements or frameworks designed to encourage repeat play, are not included in the scope of this work. However, dynamic difficulty adjustment systems are an important factor to consider in sustaining motivation to play. Existing work that addresses motivating players to repeat their use of exergames does not often include the question of how the game can evolve to keep challenging the player. The game systems described in the present work are designed to not only challenge players at different fitness levels but also to support continual challenge for a player, should they engage in multiple sessions of a game over a longer period of time (multiple weeks or months). Also, it is likely that players would be motivated to play a game that is able to help them achieve fitness goals. For an exergame to do this, it needs to provide effective exercise. Following exercise guidelines and creating games that support different types of exercise at sufficient intensity levels is one way to do this.

1.5.2 Attractiveness-Effectiveness Balance

The balance between game and exercise elements is considered in the design of each of the exergames we have developed. The main reason behind using games for exercise is to leverage the enjoyment, immersion, motivation, and interest that games bring to the table, and so our goal is to create fun experiences that incorporate physical movement instead of pursuing a direction similar to some existing exercise games, which is to use software and gaming technology to support more traditional forms of exercise. In most of our games, we aim to implement game mechanics using forms of movement that are natural to players in addition to supporting sufficient exercise intensity. Many existing exergames focus on traditional exercise routines (e.g. yoga, series of squats or lunges, kickboxing movements, walking or running) and it is easier to understand that these activities are effective. However, we have an opportunity through exertion game design to allow players some choice in how they move, and take advantage of games' capability to encourage creative play. In existing work that discusses the design of exergames that are both enjoyable and effective, little mention is made of the possibility to design for fun physical movement, in addition to fun game elements and effective physical movement.

1.5.3 Social Interaction

The importance of social support in exercise programs, and the benefits that social interaction can bring to exercise activities or games is recognized in the literature (see for example Mueller, 2003, 2008, 2010 on exertion games with a focus on social interaction), but the present body of work does not examine social interaction in exergames.

1.5.4 Platform

The games presented in this work, with the exception of the original Astrojumper game, all use the Microsoft Kinect. This device was chosen for several reasons, primarily for the ease with which the Kinect tracks a player's entire body, allowing us to design our games to support full-body motion. Also, the Kinect does not require the player to be physically connected to any system that might restrict the player's movements. The Kinect is also commercially available hardware and is relatively easy to acquire and use in any space with sufficient room to move around, unlike the CAVE virtual reality system used in our early experiment with the Astrojumper exercise game (described in section 4 of this paper). Finally, the aforementioned ability to track the player's entire body results in a player movement dataset that we may examine in detail, revealing how players react to presented game obstacles when a specific physical action is or is not required, or how players respond when the game mechanics are or are not intuitive. Also, importantly, we can use this dataset in conjunction with physiological data collected during play and thereby discover which movement types correlate with the best physiological results, for example, sustained, elevated heart rate or energy expenditure consistent with moderate to vigorous exertion.

1.5.5 Safety

In exercise gameplay, as in many other activities that involve physical movement and exertion, there is some risk of sustaining physical injury. Investigating the particulars of safety considerations in exertion interface design was not a focus of our research, but we will briefly address these concerns.

First, we will note that the games discussed in this work were not designed for physical rehabilitation. Exergames with this purpose clearly need to guide users carefully through much more specific movements with the intention of helping them overcome physical damage. Our games, however, are intended for use by those who are reasonably healthy or have no serious restrictions on the forms of activity they are able to engage in, as a means of entertainment with the additional benefit of being able to contribute toward physical activity goals.

We put some amount of effort and testing into designing exergame mechanics that did not require players to perform motions involving unusual straining or bending, or to repeat potentially uncomfortable movements. Most of our games, especially Astrojumper and Legerdemain, allow players quite a bit of leeway in deciding how they want to move to address presented challenges and accomplish game goals, which potentially reduces the risk of injury as players will most likely choose to perform movements that feel most comfortable to them. Additionally none of the types of movements designed to be part of gameplay fall outside of normal expectations for a workout or everyday activity involving the type of exertion each game represents.

All game studies were conducted in controlled lab environments where we reduced the risk of injury as much as possible, by keeping the gameplay space clear of obstacles and keeping water, crackers and a first aid kit available. Participants were fully informed about the type of activities involved in study procedures and notified that they could discontinue participation at any time, but of the approximately 200 players who participated in the combined studies, none dropped out or reported injury. However, if exergames such as these were to move past the prototype stage and be used in longer-term studies, studies with different participant groups such as an older population, or to become commercial, more extensive safety testing under the supervision of health professionals would need to be conducted and appropriate changes implemented, or warnings made available as part of the software, as is done in existing commercial Wii and Kinect games.

1.6 Scope

In order to focus the intended contributions of the research described in this paper, the following areas are considered as outside the scope of our work.

1.6.1 Psychological Factors in Motivation to Exercise or Play

Section 1.3 describes some of the research challenges for exergames relating to motivation. These include designing exergames in line with individuals' goals or reasons for exercising, or game factors that affect users' continued interest in games over time. A study of player psychology underlying these issues is for the most part considered out of our scope. We focus on players' experiences in a single, individual play session, evaluating enjoyment, flow experience and mood, and the exploration of game system implementations meant to support repeated play through adaptable, sustainable physical challenge. We do not concentrate on the psychological issues of encouraging initial or repeated play, although we may occasionally mention aspects of gameplay, such as the variety that results as our game systems adapt to individual player abilities, or of player responses that could have some positive effect on player motivation. For the most part we assume the presence of motivation to engage in an exergame experience, and consider the issue of finding specific motivating factors a potential focus of future research.

1.6.2 Long-Term Play Resulting in Health Benefits

Evaluations of the exercise effectiveness of games described in this work are based on physiological data collected from players during individual play sessions. For instance, we evaluate gameplay for its ability to elicit elevated heart rates and an appropriate level of exertion intensity, which we define in most cases as moderate intensity. The results of these single game sessions are interpreted as indicators of the games' capacity to provide health benefits should they be played repeatedly over some period of time. However long term studies, in which repeated game sessions take place across multiple weeks or months, that observe the exact effects on player fitness or body composition that result from repeated gameplay are outside the scope of the present work. There is much to be learned about exergame design and creating improved player experiences that effectively use the full-body play capabilities of current technology, and this work focuses on establishing basic principles through single-session experiments, leaving longer-term studies for future research.

1.7 Approach – Outline

The steps taken to address the research questions listed above are discussed in this paper as follows:

- In section 2.1 we will briefly discuss current, commercial exergames and their relative abilities to achieve attractiveness and effectiveness as defined by Sinclair et al. (2007).
- A review of past exergame research will be presented in section 2, including an overview of work representative of current research directions, and a focus on published exergame design theory and relevant empirical evaluation that informs our own work.
- Sections 3 - 8 will describe the goals and design approach for each of the exergames we have developed, putting exercise guidelines and existing design theory into practice. Results from user studies evaluating psychological and physiological responses to individual games will also be included.
- A comparison of players' experiences across games and results from our final user study of flow experiences in exergames will be presented in section 9.
- We will conclude with a discussion of the insights that we have gathered from applying our exergame design approach, developed around existing gameflow theory and exercise guidelines, to a collection of exergames that support multiple exercise types.

CHAPTER 2: LITERATURE REVIEW

2.1 Commercial Exergames

Exergames that have been commercially developed for the Wii, PlayStation or Xbox 360 consoles and their peripheral motion-sensing devices fall into several categories. The largest of these includes what may be considered technology-supported traditional exercise, as applications within this category use available motion sensing devices in activities such as yoga or pilates, boxing, routines including push-ups, jumping jacks, squats or lunges, and so on. Such activities should prove effective for exercise, but are not necessarily actual games, and the focus is on the workout instead of on "fun." A different category includes games that are not specifically designed for exercise but can be played using physical movement; any game designed to use the Wii balance board, or the Move or Kinect for example, might fall into this category. Third are games that attempt a balance between fun and exertion: these focus on activities that can provide a good workout and add more game-specific elements, such as a storyline or the ability to earn points that may be used to purchase in-game items. Dance games are included in this third category, and are notable for their support of a form of movement that can be seen as fun in and of itself.

Table 2.1: Selected commercial exergame examples.

Category	Game
(1) Technology-supported traditional exercise	EA Sports Active or NewU Fitness First Mind Body, Yoga & Pilates Workout (Wii), Your Shape Fitness Evolved or UFC Personal Trainer (Kinect), some activities from Sports Champions 1/2 (PS3+Move) or Wii Fit Plus
(2) Active, non-exercise focus	Shaun White Snowboarding: Road Trip (Wii), Kinect Adventures (Xbox and Kinect); generally any Wii or Kinect game might fall into this category.
(3) Exercise games	Walk It Out or Punch Out!! (Wii), Dance Dance Revolution (multiple platform), Dance Central (Kinect), some activities from Sports Champions (PS3+Move) or Wii Sports Resort

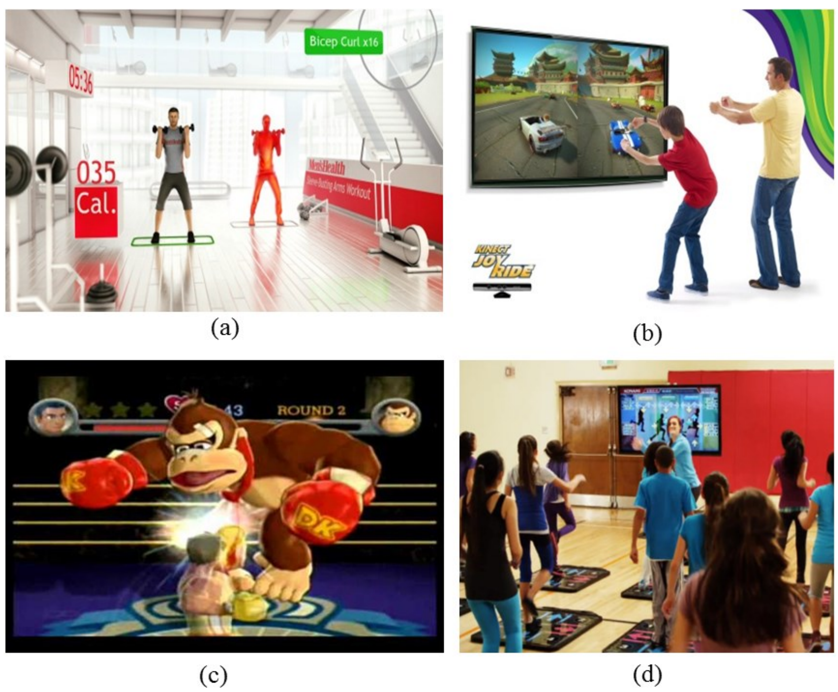


Figure 2.1: (a) Your Shape Fitness Evolved screenshot (Ubisoft, 2010, 2011, 2012, 2013; exercise programs developed with Men's Health and Women's Health magazines; more focus on resistance training). (b) Kinect Joy Ride advertisement (Big Park and MS Game Studios, 2010). (c) Punch Out!! For the Wii (Next Level Games and Nintendo; boxing game). (d) DDR (picture src: http://tpn.tv/2013/01/16/united-healthcare-puts-dance-revolution-in-schools/).

Players who approach these games with the specific intention to use them for exercise can generally do so, with the possible exception of games in the second category. However, several issues are present that decrease the effectiveness of these games as exercise tools. Applications from the first tech-supported workout category may provide the most effective forms of exercise but are not necessarily fun, and may only be attractive options for people already motivated to exercise. Applications from the third exercise games category strike a better balance between game elements and exercise. Dance Dance Revolution and its many sequel versions (Konami, 1999-2013) are popular games that are played both for enjoyment and for the benefit from the physical activity (Höysniemi, 2006). Walk It Out for the Wii (Konami, 2010) offers a unique approach to a walking game: players explore an island as they walk to the beat of the game's music to earn points, which may then be used to build various structures on the island. However, the walking movement used to play Walk It Out is not likely to be challenging enough to help many players with their fitness goals. Also, the effectiveness of exercise offered by games in this category can be negatively affected by long load times or menu navigation requirements between levels (or songs, for the dance games), or by the duration of the game itself. Wii Fit Plus (Nintendo, 2009) or Wii Sports games may last at most a few minutes, which is not sufficient time to gain health benefits that result from sustaining an elevated heart rate. One review of Wii Fit points out the problems of needing to navigate the menu after each individual activity (for example, after each individual yoga pose) and the inability to pre-select a set of activities to form a workout routine (Costantino, 2008).

These are examples of problems that can be avoided through a more careful consideration of exercise guidelines that are relevant to the game's purpose, for instance, the ACSM (2011) states that aerobic exercise sessions should last for at least 10 minutes each in order to count toward daily or weekly target amounts of exercise, so a game focusing on aerobic exertion should provide at least 10 minutes of uninterrupted exertive gameplay. This approach to exergame design is demonstrated in each of the games we have developed. On the other hand, we also wanted to maintain a strong focus on the game-centered elements of our exergames, designing for enjoyment and appeal to both those who want to use games as exercise tools, and those who just want to engage in a fun play experience. With this in mind, we took inspiration from Dance Dance Revolution, one of the most successful exergames in terms of widespread adoption.

Höysniemi's (2006) extensive study of Dance Dance Revolution (DDR) players examined how DDR affects players' physical health and social life, how they were introduced to the game, and what factors were the most important in motivating them to continue playing. Five hundred fifty-six questionnaire responses from players in the U.S. and Europe were considered, with results indicating that DDR does have positive physical and social effects. The most common reason for beginning to play was "other people," with friends or relatives recommending it, or with players being introduced to the game at social events like birthday parties. A common play style, "freestyling" or improvising, was mainly developed because players wanted to entertain or impress an audience. While social factors were the biggest reason to begin play, 55.2% mentioned health benefits as a major reason to continue, along with entertainment, self-challenge, music and performance. Twenty-three percent of the respondents were overweight, of these, the majority (87.5%) said they had lost weight because of dance gaming. Players did mention lower-body health problems (knee or joint pain, muscle cramps, etc.) caused by playing on poorly cushioned game surfaces, insufficient warm-up time, bad foot placement, or excessive play, but many players indicated that DDR helped relieve stress, promote relaxation or sleep, improve body image and self-esteem, and led to improved stamina and better muscle condition.

The above findings show that DDR is accepted as an activity that is both fun and can effectively be used in exercise. It is important to note that the game is built around dance, which is a type of movement that is itself fun or enjoyable, and its difficulty has a wide enough range to challenge a great variety of players with different physical or game-playing abilities. The dance movements, or the basic mechanic of the game which involves stepping or jumping on top of different arrows on the dance pad controller to match those shown on screen, is simple enough for anyone to learn and follow, but the mention of “freestyling” as a play style also suggests that players have space to be creative with their movements within the bounds of the presented challenge. The concept of creative movement is not often discussed by exergame researchers, but we believe it to be an important consideration in exercise game design and have applied it to our own work.

2.2 Exergame Effectiveness Studies

Researchers in health fields have produced substantial work evaluating players' physiological responses to commercially available exergames, with the goal of determining whether or not the games prompt activity at such a level as to contribute toward the ACSM-recommended daily amount of exercise. While the results from recent (2007 through 2011) literature are generally promising regarding exergames’ potential to provide fun, effective activity, not every study reaches the same conclusion.

Exercise game effectiveness studies have showed general agreement that exergames can elicit player energy expenditure equivalent to that which occurs during light to moderate intensity exercise, activities such as walking or jogging. This is sufficient to contribute to the AHA or ACSM recommended daily physical activity amounts (Bailey & McInnis, 2011; Foley et al., 2010; Graf et al., 2009; Graves et al., 2008; Graves et al., 2010 (2); Hurkmans et al., 2011; Hurkmans et al., 2010; Maddison et al., 2007; Miyachi et al., 2010). These studies were conducted with a variety of populations; children (Bailey & McInnis, 2011; Graf et al., 2009; Lanningham-Foster et al., 2009; Maddison et al., 2011; Maddison et al., 2007), adolescents (Graves et al., 2008; Graves et al., 2010 (2)), adults (Lanningham-Foster et al., 2009; Miyachi et al., 2010), chronic stroke patients (Hurkmans et al., 2011), and cerebral palsy patients (Hurkmans et al., 2010). Other studies reported additional positive results. A study of overweight and obese children playing active video games over a 6-month period showed a small but definite positive effect on BMI and body composition (Maddison et al., 2011). Parents, children and teachers view exergaming as an accessible, socially acceptable form of physical activity (Dixon et al., 2010; Fogel et al., 2010). A 12-week study of 20 children who were randomly assigned to receive or not receive an active video game package showed the children in the active game group spent less average time playing video games and higher average time with physical activities (Ni Mhurchu et al., 2008).

However, not every study has such promising results. In the study conducted by Miyachi et al., (2010), 12 adult men and women engaged in all of the Wii Sports and Wii Fit Plus activities for at least 8 minutes. The study classified 67% of all game activities as light intensity exertion and only 33% as moderate intensity exertion, with no vigorous-intensity activities. This suggests that only one-third of the 68 activities available in Wii Sports and Wii Fit Plus can contribute toward the ACSM or the AHA-recommended amounts of daily physical activity (Miyachi et al., 2010). White et al. (2011) compared the energy expenditure of 26 boys (11.4 +/- 0.8 years) engaging in a range of activities, including sedentary (resting, watching television, sedentary gaming), walking, running, and playing active games (Wii Bowling, Boxing, Tennis, and Wii Fit Skiing and Step). Although energy expenditure was significantly higher during active gaming than during the sedentary activities, no significant difference was found in energy expenditure between active gaming and walking. This led to the authors' conclusion that active video gaming is not intense enough to contribute toward the current daily activity recommendation for children (White et al., 2011). A second study of adolescents, young adults and adults playing Wii Fit activities found that moderate intensity activity was elicited by Wii aerobics for all groups, but that heart rates were lower than recommended for maintaining cardiorespiratory fitness (Graves et al., 2010 (2)). A 12-week study of children using a peripheral device to enable step-powered gaming for multiple games showed no significant changes in body fat, and no positive effect on physical activity levels; the authors stated the need for larger future trials to determine the impact of active games on children's health and physical activity (Graves et al., 2010).

The results from these studies further point toward the need to better consider guidelines or professional recommendations for exercise in the design of exergames that are able to support effective exertion through play, as we have attempted to demonstrate through our work.

2.3 Exergames in Academia

Academic exergame research investigates diverse issues from the feasibility of exertion game platforms meant to enable various forms of exercise, to the evaluation of exercise performance to enable feedback generation for players, to networking for remote collaborative and competitive play. While not all of this work is directly related to our present work, useful ideas in exergame design and implementation can still be noted. The below sections offer an overview of the different research directions and describe some of the best examples of existing work.

2.3.1 Exertion Games for Experimental Interfaces

Mueller et al. (2003, 2008, 2010) have done considerable work with exertion interfaces. They developed several networked exertion games (Breakout for Two, Table Tennis for Three, Jogging over a Distance), and evaluated how social interactions were facilitated by the games, and how the interaction affected players' game experiences. The evaluation of Table Tennis for Two looked at player experiences with the exertion interface, game engagement, and social interaction during play. The majority of players (39 of 41 players, ages 21-55) had a positive experience, and 28 of 40 players felt the game created a social bond among players. The correlation of the statements, "I liked the game," and, "The game created some sort of social bonding between me and the other players," was significant.

Höysniemi et al. (2004) presented their martial arts game Shadow Boxer, which used computer vision technology and image processing, and evolved into the game Kick-Ass Kung Fu described in Hämäläinen et al. (2005). The game is designed to be both a fun experience and a tool for training, and in the game players use martial arts moves such as punches, kicks, and other acrobatics, to defeat opponents. A user study with 46 martial arts practitioners evaluated the intensity of the game's exertion by measuring heart rate and calculating percentage of maximum heart rate reached (median 90% while fighting the game opponents).

This work involved the building of custom platforms to support different forms of full-body exertion play: Mueller's games allow players to see each other and use physical props, such as balls or a tennis table, during play; Hämäläinen's martial arts game uses real-time image processing and computer vision to place the user's image inside the game and exaggerate their movements. Full-body movement can perhaps lead to effective exercise through gameplay more so than a game that is designed to only use movement of individual limbs or parts of the body (Graves et al., 2008) but custom platforms such as those developed by these researchers are not widely accessible or easy to set up and use. We took this into consideration when choosing the platform for which to build our exergames; the Microsoft Kinect fulfilled our requirements for easily available and usable technology that could reasonably, accurately support full-body play.

2.3.2 Adding Gameplay to Traditional Exercise, or Exercise to Traditional Games

In his review of movement-based interaction interfaces, Nijholt et al (2008) mention three categories into which exergames could fall: a game experience could be added to exertion, an exertion component could be added to a game, or a game could bring together entertainment and exertion into a more unified experience. Most recent research has produced games that have fallen into the first two categories.

Ahn et al. (2009) developed Swan Boat, a multiplayer exercise game with collaborative and competitive elements that incorporated an interactive treadmill and sensor bracelets. In Swan Boat, teams of runners coordinate their speeds to steer a boat down a river, with relative running speeds determining the boat's direction, and use hand/arm gestures to attack opponents. In a two-week preliminary user study, 17 participants (11 university students and 6 professors) ran on treadmills during the first week, and played Swan Boat during the second week. Players were observed to walk or run faster while playing Swan Boat, as opposed to their speeds while using the treadmills normally (4-10 km/h when not playing, compared to speeds of 11-14 km/h (men) or 10-12 km/h (women) or even 17-18 km/h (athletes)). Several participants made comments indicative of a good experience with the game, saying that they might be more motivated to exercise on treadmills if they could play the game, or that they lost track of time while playing, which might suggest entering a flow state. These results show the benefit of incorporating gameplay with traditional exercise, motivating our own work and a comparison of the user experience in games that use a more traditional form of exercise like stretching or sit-ups, as in our Sweet Harvest and Washboard games (sections 7 and 8), and those that use less structured movement like Astrojumper or Legerdemain (sections 4, 5 and 6).

While Ahn et al.'s (2009) study developed a game for a traditional piece of exercise equipment (treadmills), previous work has also looked at adapting more traditional digital games, in addition to traditional exercises or exercise equipment, for exergaming. Berkovsky et al. (2010) created the 'PLAY, MATE!' concept, which modifies existing games to offer rewards for physical activity performed while playing, for example, bonus points or increased time to complete game levels. Several versions of an open source game, Neverball, along with the PLAY, MATE! system, were used in a study comparing participants who played a sedentary version of the game, and other versions of the game with an indirect motivation to engage in physical activity (activity halts the progress of a virtual competitor), a direct motivation (activity lets players earn more time in which to complete game levels), and both motivations. Unsurprisingly, players increased their physical activity when given some form of motivation to do so. It is interesting to note that participant activity was significantly higher in the group with the direct motivation when compared with the indirect motivation group, but no significant difference was found in activity performed while playing the direct motivation version and the version with both motivation forms (Berkovsky et al., 2010). While the work presented by Berkovsky et al. was novel game design, the way in which the 'PLAY, MATE!' system was implemented caused interruptions in both the game and exercise experiences. Physical activity, such as jumping up and down for a period of time, could be used by players to earn in-game rewards such as more time in which to complete a difficult game level. In order to begin jumping and earn rewards, however, the player first was required to pause the game, then could perform the jumping activity to gain the reward and then could stop jumping and continue the game. This sequence of events seems unlikely to promote either gameplay that enables a flow experience, or exercise sufficient to contribute toward recommended amounts, although it was successful in changing the ratio of sedentary and active play time. In our games we worked to combine exercise and gameplay into a unified experience, as suggested by Sinclair et al. (2007), in order to improve both attractiveness and effectiveness dimensions of the experience.

2.3.3 Pervasive Mobile Games and Factors in Long-Term Play

Several different studies have examined features of games that affect the motivation to play over the long term. Lin et al. (2006) developed a social computer game that linked players' daily step counts to the growth and activity of virtual fish. In "Fish'n'Steps", a virtual fish lives in a tank with several other players' fish, and a player who achieves daily step count goals will have a larger, happy fish, while not achieving a goal will make the fish angry or sad, and will affect the appearance of the group's fish tank. The researchers used the Transtheoretical Model (Prochaska et al., 1992), which classifies an individual's progress toward behavior change as occurring in a series of steps to evaluate the impact of Fish'n'Steps on the exercise perceptions or habits of 19 people over the course of a 14-week study. Four participants showed an increase in their daily step count, three changed their attitude toward physical activity, and seven showed a combination of those changes. Although the game grew repetitive with time, most participants continued interacting with it, and were motivated by the competition aspect or by an emotional attachment to their virtual fish. Games with comparative elements to Fish’n’Steps are Neat-o-games (Kazakos et al., 2008) where daily player activity controls an avatar in a virtual race, or Ubifit Garden (Consolvo et al., 2008), where activity improves a virtual garden. Although our work does not focus on social play or on motivating players to engage with exercise games over a long period of time, we can still note the role that social interaction had in motivating players to continue past the point where the simple game became repetitive, and consider ways to keep players interested and motivated in an individual session by implementing gameplay that does not feel repetitive.

While the present work does not focus on pervasive or mobile games, it is worth mentioning several mobile games to demonstrate how a game may not have exercise as its main design objective but still lead to increased physical activity as a part of gameplay, and also include game elements or factors that convince players to change their daily habits during the course of long-term play. These games can provide opportunities to take exertion play to outdoor environments, allow users to track physical activity which may prompt behavioral change in the direction of increased daily activity, and showcase various ways in which game design may take advantage of the characteristics of outdoor environments or wireless networks to define play, and support opportunities for creative or emergent play. Some games for mobile platforms may also be installed in public locations, for instance, Kurdyukova and Rehm's (2009) competitive exertion game installed at a bus stop, the duration of which is too short to provide real exercise, but that can offer a way for passersby to include a small amount of added physical activity to their daily routines.

Tiensyrjä et al. (2010) developed a pervasive, location-aware, multiplayer game called panOULU Conqueror where teams of players could score points by "conquering" real-world network access points. Elements of the game included the access points, which could be friendly (owned by the team), neutral, or hostile; the players, who had level and strength characteristics, attack points, and experience points; and random events, which gave different, temporary abilities to players. 96 players in 31 teams played a four-week tournament, and the authors used post-game online questionnaires and focus group interviews with the most active teams to evaluate the most successful elements of the game, and how the game's social aspects helped to create an engaging play experience.

Forty-nine percent of respondents reported that the game increased their team's sense of community, and several reported altering their daily schedules for the game. The main motivating factors for the top two teams were social interaction (meeting with team members, friends in other teams), getting physical exercise, and the interesting concept of the game.

Flintham et al. (2003) developed a chase game called Can You See Me Now? that explored interactions between players, some of whom played through an online interface and others who were outdoors moving around the streets of Sheffield in the UK. In this game, online players moved avatar icons around the shared city map using keyboard controls, and the outdoor players, or “runners,” physically traveled through the streets to get close enough to ‘catch’ the online players, as determined by their GPS-tracked positions. In Bystanders, a second version of the game, the outdoor players were guided along a specific path by the online players. Flintham et al.’s work focused on the technical challenges of overcoming GPS inaccuracies, but the concepts presented offer several interesting game design ideas for outdoor, mobile exergames where players compete or collaborate with other players or trainers. Also, some considerations for the design of outdoor games, or games played by those who may be focusing on their movement or environment rather than the game display, are included that can inform the design of our exergames also, and these are further discussed in the below section.

2.4 Exergame Design Theory

Section 1.3 described the need for exergames to motivate repeat play and the importance of balancing game and exercise elements. Researchers in exergame design theory have often centered their work on these two challenges. A player will be motivated to spend more time with a game that is enjoyable, and several authors have done considerable work to model the elements that contribute to game flow as the key component of enjoyment. Researchers have also developed frameworks and heuristics for exergame evaluation, which we will review below and later discuss their influence on the design of our own games and game studies.

Sweetser and Wyeth (2005) reviewed the literature on player enjoyment and the heuristics that had been used to predict it, which for the most part were based around the interface (controls and display), mechanics (interacting with the game world), and gameplay (problems and challenges). They composed these concepts into one model of game flow, building on psychologist Csikszentmihalyi's (1990) original eight elements of a flow experience and mapping them into a video game context. Their eight core elements of flow in games include concentration, challenge, skills, control, clear goals, feedback, immersion, and social elements. According to Sweetser and Wyeth, to create a flow experience games must be able to hold a player's concentration through a high workload, game tasks must be sufficiently challenging to be enjoyable, a player must be skilled enough to undertake challenging tasks, and the tasks must have clear goals and provide feedback so that the player feels a sense of control over the tasks. Their work states that these elements will promote flow, or a sense of complete immersion in the game. Social interaction is also mentioned as an element of enjoyment although it is not relevant to all types of games, and it does not map as clearly onto Csikszentmihalyi's flow components: social interactions can often disrupt game immersion, but people will play games they do not find as enjoyable in order to engage in social interaction, so game designers should consider providing opportunities for competition and cooperation (Sweetser & Wyeth, 2005).

To validate their flow-based model of player enjoyment, Sweetser and Wyeth used the model to evaluate two real-time strategy games using the criteria listed for each element of the model, for example, criteria for the ‘challenge’ element say that the game should increase the level of challenge throughout and provide different levels of challenge for different players; criteria for the ‘feedback’ element say that the game should provide players with immediate feedback on their actions, and so on (Sweetser & Wyeth, 2005). While using only two games from a single genre may not constitute a very thorough validation of the enjoyment model, the elements of the model are still intuitively reasonable and grounded in previous flow research. However, it should be pointed out that while some of the model’s elements and related evaluation criteria are helpful to a game designer aiming to create a flow experience, such as those for challenge, player skills, clear goals, and feedback, other model elements only seem to involve what players should experience if the previously mentioned, more concrete elements are in place. Immersion, as an element of the model, is perhaps the best example: immersion is an abstract concept that itself cannot be implemented in a game. Instead, game systems may effectively develop player skills while balancing challenge with ease leading to a feeling of immersion during play. We used the concepts put forth in this work to help design and evaluate our games, and will later discuss possible clarifications of this model, further informed through our exergame design experiences.

Sweetser and Wyeth’s (2005) gameflow components have also been analyzed within the context of pervasive games. Jegers (2007) responded to the concentration element included in Sweetser and Wyeth's model, which said that players should be able to concentrate on the game, and noted the need for pervasive exergames to be designed in such a way as to allow players to split their attention between the game tasks and the surrounding environment as needed, without losing their concentration or sense of immersion. In a similar vein, Soute and Markopoulos (2007) introduced the concept of a 'Head-Up Game,' which is a game that may be played outdoors as in traditional outdoor children's games, requires physical activity, and is enhanced by technology. Soute and Markopoulos (2007) point out that relying on device displays for game information halts physical activity as it forces a player to look down at the screen; with this in mind, they lay out principles for designing "Head-Up Games" which include the following: the game should use technology that is simple and reliable, should require only minimal work to move and install in any location, should provide for rich social interaction, and should make use of imagination as opposed to solely relying on a visualization of a virtual world. Hendrix et al. (2008) later conducted a study of games developed according to the "Head-Up Games" concepts. These principles do not only apply to pervasive games, those developed for mobile platforms or those designed to be played in outdoor environments, but also to games such as those presented in our current work. In traditional gaming, it is usually the case that a player will be focusing the bulk of their attention on the display screen, and little or no movement away from that visual point of focus is necessary. However, physical exertion introduces a potentially distracting factor into gameplay, and designers should keep this in mind while considering game instructions or feedback elements, working to ensure these elements are clearly communicated even if a player’s movements temporarily remove their focus from parts of a display.

Suhonen’s (2008) thesis organizes a set of evaluation heuristics taken from the literature, and demonstrates their use in estimating health game usability, gameplay (including tasks, goals and skills; feedback; pacing, strategies and game structure; and player experience), game story, game content and education, social interaction and multiplayer elements, and mobility (how quickly the game can be started, ease of incorporation with surroundings, or play interruption handling). Table 2.2 shows an abbreviated selection of these heuristics; readers may note the overlap with Sweetser and Wyeth’s design considerations. As Suhonen’s work is intended to apply not only to exercise games but to other health education games as well, not all of the heuristic modules are relevant to the games we have designed, but have been included as a mention of game usability or enjoyment design considerations not already mentioned above.

Sinclair (2007) looked specifically at how two important dimensions of an exergame interact. These dimensions are attractiveness, referring to the elements that make gameplay enjoyable, and effectiveness, referring to the exercise-specific elements of the exergame. A successful exercise game must be both attractive to the player and effective in the exercise it provides. Based on a review of existing exergame systems, Sinclair developed the attractiveness-effectiveness dual flow model, pictured in Figure 2.2.

Table 2.2: Selection of game evaluation heuristics from (Suhonen, 2008).

Heuristic Module	Heuristic Examples
Game usability (incl. interface and mechanics)	• The game gives immediate and meaningful feedback on the player's actions. • The interface is as non-intrusive to the player as possible. • Mechanics feel natural and have correct weight and momentum.
Gameplay (ex. tasks, goals, skills, strategies)	• There is a clear overriding goal of the game presented early; there are multiple short-term goals throughout the game at appropriate times. • One reward of playing should be the acquisition of skill. • Game tasks should match the player skill level without being discouragingly hard or boringly easy.
Game story (story, characters, world)	• Player is interested in the story line. The story experience relates to their real life and grabs their interest. • The player has a sense of control over their character.
Content and education (educational goals, integration, effectiveness)	• Targets/Goals are tailored to the developmental and instructional level of game users. • Feedback provided in response to incorrect actions offers an opportunity for learning also.
Social interaction and multi-playing (social and multiplayer features)	• The game supports communication; there are reasons to communicate. • There are ways to cooperate/compete with other players. • The design hides the effects of network (in online gaming).
Mobility (mobile games)	• The game and play sessions can be started quickly. • The game accommodates with the surroundings.

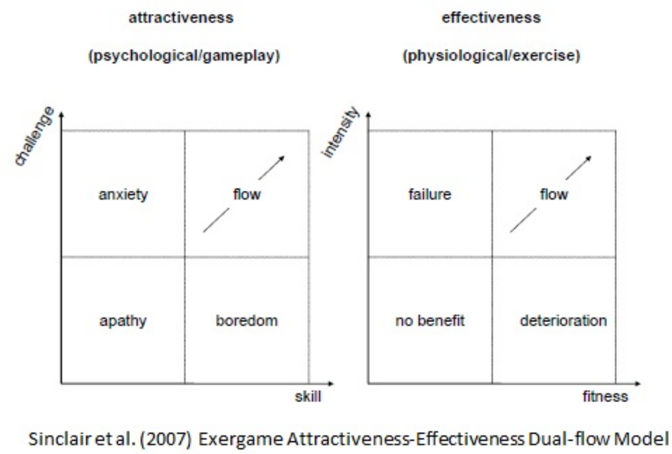


Figure 2.2: Sinclair et al. (2007) Dual-Flow Model.

Sweetser and Wyeth's flow model is used to describe the attractiveness dimension, while the effectiveness requirement is fulfilled by a game that provides exercise of the recommended duration and frequency (e.g. adheres to the ACSM guidelines). Additionally, Sinclair states that one important consideration for attractiveness is to realize how an input device affects flow components. For example, a player can more easily concentrate on a game while pedaling a stationary exercise bike than while running on a treadmill; a Dance Dance Revolution player can focus on the dance pad game controller because the game's display is relatively simple. For effectiveness, the intensity and type of exercise must be considered, along with the need to adjust game difficulty based on a player's physical ability (Sinclair, 2007). While Sinclair was one of the first authors to discuss the need to consider flow in both psychological and physiological dimensions of an exergame experience, his model separates them completely while we believe there is a space in which they overlap, namely through a game’s support of enjoyable physical movement.

Campbell et al. (2008) and Consolvo et al. (2006) offer some further design considerations for games or applications that are meant to encourage physical activity. Campbell et al. attempted to identify the most important design principles of everyday fitness applications (whose purpose is to integrate physical activity into everyday life) by examining both previous fitness applications and the factors that make some games, like Blizzard Entertainment's World of Warcraft, so successful. Their results echoed earlier work in finding that core game mechanics should be easy to learn yet hard to master, micro goals allow the player frequent gratification and a means of judging progress, and players of similar skill should be matched when playing together (or a player who is behind might be given a temporary advantage) (Campbell et al., 2008). Consolvo et al. developed Houston, a mobile phone application that allows daily step count logging, goal forming, gives feedback on progress, and supports progress sharing and communication with fitness group members. Four important design considerations put forward by Consolvo et al.'s work also reflect those from earlier work, and include 1) give users proper credit for their activities by providing information that is sufficient and as accurate as possible; 2) support personal awareness of activity level, perhaps by providing a history of past behavior as well as current status and activity level performance; 3) support social influence, as social pressure, support, and communication can be major motivating factors in goal achievement; and 4) consider the practical constraints of users' lifestyles in determining the technology to use, and how to set goals (Consolvo et al., 2006).

While the majority of researchers use flow as a model for game enjoyment, alternative approaches to exergame evaluation have occasionally been taken. Adams et al. (2009) attempted a learning, or operant theory approach to coding game elements with an emphasis on feedback for actions taken. The purpose of this approach was to begin identifying particular game elements that lead to behavioral changes among players, but the work was preliminary and not developed so as to be practically useful for exergame designers and developers. Additionally, Yim (2007) explored the sports psychology literature on how games can be used to increase exercise motivation. People with low self-efficacy, a poor exercise self-image, and a lack of peers to exercise with will often have more trouble adhering to exercise programs. Based on his literature review, Yim made the following recommendations for exercise games: an exergame should integrate music, as upbeat music can decrease feelings of anger, fatigue and depression; leadership should be provided to novice players by educating them about health and offering encouragement; achievable short- and long-term goals should be provided; the player's fitness level should be hidden (to encourage comfort and confidence); and finally, the game should avoid mechanics that separate players and prevent grouping and instead actively help players form peer support groups.

Other research agrees with the design considerations proposed in the above work (Baranowski et al., 2010), namely that the design of an exercise game should include traditional game design considerations that make a game enjoyable, playable and motivating (clear goals and feedback for actions and accomplishments, interactivity and a sense of control for the player, challenge/player skill development balance, and so on) while balancing factors relating to exercise (consideration of players' skill levels and what forms of exertion play lead to effective exercise). This research is influenced by these considerations, and also the goal of supporting players' concentration on game tasks through steady, constant game progression. Suhonen's (2008) collected heuristics are also of use. For example, we use physical actions designed to feel natural for players as game mechanics, and our difficulty adjustment systems match game challenge with player skill levels. We also build on Sinclair et al.'s (2007) work, described above, which contains some of the best discussion of the balance between game and exercise elements, although for the most part it separates the dimensions of gameplay and exercise without mention of possible overlapping design areas.

While these theoretical design considerations have been used to different extents by researchers developing custom exercise games, not all of these studies have involved an examination of the resulting player experience. In the below section, we will provide a brief review of past research that has focused on aspects of player experience, and its influence on our own work.

2.5 Use of the Flow Concept in Player Experience Studies

A recent workshop paper (Wyeth et al., 2012) touches on the gaps in our knowledge of player experiences when playing traditional video games, and discusses briefly the different ways in which the player experience can be viewed, which include subjective feelings during play, motivations to play video games, and the potential impact that different game designs or content may have on the experience. Exergames, which add a physical aspect to gameplay, may present additional questions regarding how play is experienced. When examining player experience, Chen (2007) states that the concept of flow is used often because of the intuitive relationship between challenge and ability. Several researchers have worked to translate the requirements of Csikszentmihalyi's original flow concept into a video game design context; their models are compared in the below chart from Pavlas (2010).

Table 2.3: Reproduced from (Pavlas, 2010).

Flow Requirement	**Sweetser & Wyeth (2005)**	**Cowley et al. (2008)**	**Jones (1998)**
A task to accomplish	The game itself.	The complete gaming experience.	Levels provide sub-tasks that lead to completion of whole task.
Ability to concentrate on task	Game provides interesting stimuli & workload.	Presence; Dedicated gaming environment	Creation of convincing worlds to draw users in.
Clear task goals	Primary and intermediate goals are presented.	Missions, plot lines, and levels.	Survival, collection of points, gathering of items, solving puzzles
Immediate feedback	Feedback is provided via status, score, and progress indicators.	Rewards and penalties.	Actions have immediate consequences. Shooting an NPC causes a result, picking up an item moves it.
Sense of control over actions	Player is able to move their avatar(s) and feel control over input devices.	Familiarity or skill with controls, knowledge of game conventions.	Mastering physical inputs such as keyboard or mouse.
Deep but effortless involvement	Game environment should transport player emotionally/viscerally.	High motivation to play, emotional draw to content.	Fantastic environments remove suspension of disbelief and engage players.

Several studies by educational game researchers have gone beyond suggesting flow as a useful construct, and have looked at the benefits of serious games that promote flow, linking it to positive learning outcomes (Choi et al., 2007; Harley, 2003; Pavlas, 2010; Webster et al., 1993). Flow has also been connected to increases in positive affect (Rogatko, 2009), and this is relevant since other studies have shown that positive affect can impact motivation to participate in exercise activities (Russel & Newton, 2008; Soundarapandian et al., 2010). While multiple studies of player experience in traditional video games have been conducted using variations of the flow concept (Nacke et al., 2008), fewer researchers have used exergames in similar flow studies.

One such study was conducted by Thin et al. (2011) comparing the play experiences of 14 young adult males participating in exergame activities and a cycling exercise. Six different exergames were used, including two Sony PS2 games that utilized the EyeToy camera, and four Wii games that utilized the Wiimote controllers (tennis and boxing) and the balance board (step aerobics and hula hoop games). Participants engaged in these games and the cycling exercise in random order, for approximately six minutes each with three-minute breaks in between. Heart rates were monitored throughout, and in the break between each activity participants rated their level of perceived exertion using the Borg (1982) RPE scale and responded to several visual analogue scales that evaluated their perceived game difficulty and mood state. Once all activities were completed, participants were given Jackson and Eklund's Flow State Scale-2 (FSS-2, 1992) questionnaire in order to measure the extent of flow experienced throughout the study. The multiple short activity sections, each involving different equipment and separated by rest breaks and scale questions, may have negatively affected the quality of data gained from the FSS-2 questionnaire, but the authors did have several notable results. Interestingly, flow scores from the FSS-2 were found to be closest to published values for sports, as opposed to traditional exercise or dance. When compared with published mean scores for exercise activity or dance, the flow dimensions of challenge-skill balance and action-awareness merging were significantly higher for exergames. Also interesting from an exergame design standpoint was the finding that while the perceived difficulty of games did not appear to affect players' level of enjoyment, the games that were rated as the most enjoyable employed more aggressive forms of physical movement such as punching or striking in gameplay, perhaps explainable by the very short feedback loop between such actions and their in-game consequences. Section 9 of this paper will further discuss Thin et al.'s results (2011) as some similar measures were used, and results found, in the player experience study of our custom exergames.

Chen's (2007) article describes how different players' abilities or preferences for levels of game challenge result in different "flow zones" for individuals, and mentions that although people do have a degree of tolerance for situations that temporarily move outside their ideal flow zone, those differences present a challenge for designers attempting to consider many players' needs. The inclusion of game difficulty levels to satisfy these individual needs quickly becomes infeasible. A potential solution to this problem lies in the addition of game systems for dynamic difficulty adjustment, which monitor an individual's performance in a game, and use that performance data to determine an appropriate game difficulty level. One of the main research questions addressed by the present work deals with dynamic difficulty adjustment systems that are able to tailor a game's level of challenge to match individual players' abilities. The following section reviews past work that has considered such systems for exergames.

2.6 Game Systems for Dynamic Difficulty Adjustment

Zhang et al. (2011) developed a virtual reality marathon game for treadmills that implemented several considerations we aim to include in our own work, including design for player immersion, inclusion of the warm-up, workout, and cool-down exercise phases as described by the ACSM (Whaley, 2005), and a game system that adapts to player fitness levels to tailor exertion difficulty. Their difficulty adjustment system monitored player heart rate through the treadmill sensors, alerted players if their heart rate was higher or lower than recommended boundaries, and used the heart rate data to adjust the game difficulty by increasing or decreasing the speed of in-game opponents racing against the player. An evaluation of the virtual marathon system focused on asking participants about their experiences using the system.

Other games have also used heart rate data to adjust the difficulty of game play to suit players' ability levels, or to alter game difficulty in order to balance play between players with different fitness levels, and allow less fit players to compete with more fit players. The work done by Stach et al. (2009) provides an example of how this skill imbalance may be rectified, by using a heart rate scaling formula that can be used to base the physical aspects of competition on effort and gameplay, instead of individual fitness levels. A study of their racing game, "Heart Burn", showed that their formula was fairly effective in closing the performance gap between players of significantly different fitness levels, although less so for players of more similar fitness levels.

The Cateye Gamebike, which works as a PlayStation 2 controller and is used by Sinclair et al. (2010), is also able to detect player heart rate which, in conjunction with a calculated target heart rate, was used to adjust the Gamebike's pedaling resistance level in order to help players maintain an elevated heart rate; Sinclair et al.'s simple platform game also took into account a warm-up period which preceded a main workout period, followed by a cool-down.

The Bug Attack and Speeding games developed by Koivisto et al. (2011) uses the collective heart rate from teams of players as game input, but heart rate increases only determine how well the player teams do in the game and are not used to influence game difficulty. Kiili and Merilampi (2010) describe their prototype games, developed using mobile phones, including Tug of War, in which teams of players perform squat movements as frequently as possible to win in a game session that lasts between 30 seconds and two minutes. They discuss but do not implement several possibilities for sensors or techniques that could be used to detect effort and adjust gameplay accordingly, or to prevent cheating (Kiili & Merilampi, 2010). Wylie and Coulton's (2009) Health Defender mobile game uses a measurement of the player's initial heart rate to calculate different heart rate bonus thresholds that players attempt to reach through physical activity, e.g. jogging in place, while playing the game. Nenonen et al. (2007) use heart rate measurements to control Pulse Masters Biathlon, a skiing and shooting game, by making skiing speed proportional to heart rate and thereby motivating players to exert themselves if they want to succeed in the game. Masuko and Hoshino (2006) design a boxing game that uses the player's heart rate to determine which intensity movement to instruct the player to perform next, in order to maintain a heart rate consistent with moderate-intensity exertion.

All of the above games use heart rate measurements acquired using sensors integrated within their different hardware platforms – specialized treadmills, game bikes, and so on. This is a fine approach; heart rate is a good way to determine the amount of effort being expended. However, not all of these platforms are widely available. The exertion game design principles from (Soute & Markopoulos, 2007) recommended that the technology used by games should be simple, reliable, and require only minimal effort to install in any location, so it seems reasonable to believe that exertion games designed for a simpler platform than the abovementioned would be more easily usable and accessible for a wider population. Our goal has been to use an accessible hardware setup for our exergames that is easy to install and does not require the use of many extra sensors, so we have focused primarily on development using the Microsoft Kinect, which can be connected to an Xbox 360 console or computer. This device is widely available, relatively easy to use and effective at detecting full-body movements. It does not include heart rate sensors and using such would complicate the platform, so unlike the above, our work with dynamic difficulty adjustment systems has focused on solutions that do not use heart rate as input, instead using data that is collected solely through tracking player performance during a game, and then balancing game challenge with estimated player skill and physical effort.

Our present work builds on the reviewed previous research as it explores new forms of full-body exertion play, contributes to game design insights, and presents several unique game designs that target specific types of exercise and game systems aimed toward sustaining challenge. The following section will include an overview of the exergames that we developed in order to investigate additional elements of exergame usability, attractiveness or exercise effectiveness, and describe tools used in our exergame evaluation studies.

CHAPTER 3: EXERGAME RESEARCH OVERVIEW

Our primary research questions, introduced in section 1.4 and restated below, focus on the issue of increasing attractiveness and effectiveness traits in exergames. That is, we focus on the problem of designing an exergame that 1) is centered around exercise but is as enjoyable as a traditional video game, appealing both to people looking for a fun exercise program and those wishing mainly for entertainment; and 2) uses gameplay to support physical exertion sufficient for contributing toward the gaining or maintenance of health benefits.

Research Questions:

- Attractiveness: What additional insights into designing for exergame usability or attractiveness may be gained through the study of existing design theory, and its application to exergames with different exercise goals?
- Effectiveness: How could established guidelines for exercise be better incorporated into exergame design, in order to improve the effectiveness of exercise provided through play?
- Attractiveness-Effectiveness Balance: How could we implement game challenge adjustment systems that dynamically evaluate player performance and appropriately modify game difficulty? What balance of exertion and play is most successful from a player experience perspective?

To pursue this research, we have developed several custom exergames. In order to investigate methods by which to increase exergame effectiveness, a main goal for each game has been to focus on a different type of exercise, as ACSM guidelines highlight the importance of including a variety of exercise types (aerobic, anaerobic, and so on) in a balanced workout program (Garber et al., 2011). Other relevant exercise guidelines may also be incorporated into the game structure. Throughout, we have explored how players may be encouraged to engage in the selected forms of exercise with new movement-based mechanics and game elements, and considered how dynamic difficulty systems may be put in place to support exercise and game difficulty balancing objectives. Also for each game, we have evaluated psychological responses from players, along with physiological reactions, in order to determine game elements that contribute most toward exergame attractiveness and effectiveness.

The question of how to balance between the attractiveness and effectiveness dimensions has been approached in two ways. From a technical standpoint, we have explored the implementation of various dynamic difficulty adjustment systems that monitor player performance and automatically, immediately, modify the game's level of difficulty. Ideally, this helps to physically challenge the player while keeping them engaged and without frustrating them. Second, from a player experience perspective, we have evaluated psychological responses, including flow experiences and mood states, to a set of games that differ along spectrums of physical challenge and gameplay complexity. Each of the game studies we have conducted have offered additional insights into how entertaining and effective exergames may be designed; below, we will briefly describe how each of the studies are related, and summarize the methods used in game evaluation.

3.1 Exergames in the Present Work

Astrojumper was our initial exploration into the development of a game for aerobic exercise, which is one of the most common and straightforward forms of exertion for an exergame to support. The original Astrojumper game was developed for the Cave Automatic Virtual Environment (CAVE) system and a study was done to evaluate the effectiveness of its gameplay as an aerobic activity and its appeal to players in a variety of age groups. Astrojumper was a novel game, and the results from this study afforded several insights into how a successful exergame could be structured. The Astrojumper game and its user study are detailed in section 4.

The Microsoft Kinect became available in 2010, and following the arrival of the Flexible Action and Articulated Skeleton Toolkit (FAAST, Suma et al., 2011) Astrojumper was ported to work with PC and Kinect. Astrojumper-Intervals was our second game project: a new version of Astrojumper that was restructured based on an interval training schedule and expanded to include several new forms of motion gameplay. The project's goals were to improve upon the original Astrojumper game in both attractiveness and effectiveness aspects, and a comparison study of the two game versions was conducted to test success in meeting these goals. This project allowed us to learn more about effective and fun exergame design, the effect of increased physical challenge on player engagement, and the use of different game mechanics that encourage different types of movements from players. The Astrojumper-Intervals game and the comparison study are detailed in section 5.

Following successful experiments with the Astrojumper games, we investigated further into exergame attractiveness and effectiveness components by focusing on games able to support different forms of exertion, and player reactions to more experimental game mechanics. In our third exergame, Legerdemain, we experimented with mechanics aimed at supporting resistance or strength training in addition to aerobic activity. We performed an initial user study of Legerdemain focused on evaluating the game's success at supporting the intended exercise type, while also collecting player responses to the gameplay and mechanics. Section 6 describes this game and its study results, and how we were able to use the player feedback from the study to further improve the game.

Additional exergame prototypes were developed to allow further experimentation with different forms of exercise. Washboard involved a short workout, highly focused on sit-ups as a means of targeting core muscle groups, at a more intense level of physical difficulty than any of our other games. Sweet Harvest, in contrast, supported very light exertion through a variety of stretching and dynamic warm-up activities. Both of these games, along with Astrojumper-Intervals and an improved version of Legerdemain, were used in a fourth study focusing on evaluating player experience. This study gathered information on players' flow experiences and mood states, and allowed some comparison of exergames that were similarly developed but were each different in the type and level of physical challenge presented and the complexity of gameplay required. Table 3.1 summarizes the focus areas of each game. Washboard is described in section 8, Sweet Harvest in section 7, and the player experience study procedures and results in section 9.

Table 3.1 Exergame Focus Areas

Exergame	Area of Focus
Astrojumper and Astrojumper-Intervals	Aerobic activity
Legerdemain	Combination of aerobic and strength training activity
Sweet Harvest	Dynamic warm-up activity and stretching
Washboard	Core strength training with sit-ups

3.2 Evaluation Measures

We conducted user studies to evaluate players' physiological and psychological responses to each of our games, and these data allowed us to examine each game's attractiveness and effectiveness value. Player enjoyment is one essential part of game evaluation, and so in each of our game studies we gathered both quantitative and qualitative feedback from participants on their experience with the game. A successful exergame will afford players an enjoyable experience but will also let players feel like they have gotten an effective workout of some type (e.g. an aerobic workout from Astrojumper, or a core muscle workout from Washboard), and so we analyzed the extent to which physiological data collected during gameplay supported our hypotheses regarding effective exercise. The game studies used relatively similar approaches and measures, and we will describe some of those that were commonly used below. Individual study procedures and results will be described in later chapters on the individual projects.

3.2.1 Evaluating Effectiveness

3.2.1.1 Use of Guidelines for Exercise Type and Workout Progression

Each of our game projects involved a small set of specific goals centered on some desired type of exercise; these goals and related study hypotheses were informed by ACSM- and CDC-published exercise guidelines. We began with games intended for aerobic exercise (Astrojumper and Astrojumper-Intervals) and used these projects to develop our approach to exergame design, which we then applied to games that could support other exercise types: a mix of aerobic and resistance exercise (Legerdemain), core strength training (Washboard), and a pre-workout dynamic warm-up including stretches (Sweet Harvest). Published exercise guidelines led us to incorporate not only different exercise types into each game but also taught us to consider exercise program structure, for example, each game design took into account the need for a warm-up period before the main workout began. Sweet Harvest, which is a warm-up game, still started with easier stretching exercises and slowly increased the difficulty or intensity of the types of movements used to play. The other games implemented opening sections of easier, slower gameplay that served both as warm-up periods and as tutorial segments that allowed players to get used to the game rules and mechanics before moving into the main workout.

3.2.1.2 Evaluating Exercise Intensity and Dynamic Difficulty Systems

In our game studies we used several methods and unobtrusive sensors to collect physiological data from exergame players. Collecting data on player height, weight and age allowed us to categorize participants by weight range (underweight, normal weight, overweight, or obese) using the Body Mass Index (BMI) heuristic (CDC, 2011), and survey questions were used to collect information about participants' exercise habits. These data were used along with heart rate, energy expenditure, and rating of perceived exertion (RPE) measurements to evaluate the intensity of exertion elicited through gameplay.

We used published ACSM and CDC guidelines to form hypotheses regarding desired results. For example, one way to evaluate the success of Astrojumper's aerobic exercise was to compare heart rate, energy expenditure and RPE measurements taken from study participants with published, target ranges for aerobic exertion. Most available data regarding the use of these measures centered on cardiorespiratory exercise (Garber et al., 2011) meaning that the hypotheses we were able to form from them were most useful in evaluating games with an aerobic activity component, like the Astrojumper games or Legerdemain. Still, they were of some use in evaluating exertion intensity for Washboard and Sweet Harvest, which supported other forms of exercise. The below chart is a sample of data from published ACSM guidelines showing RPE and energy expenditure (METs) ranges for aerobic exercise at various intensity levels. In order to evaluate game intensity, we were able to compare our participant data to these guidelines.

Table 3.2: RPE and METs ranges for Cardiorespiratory Endurance Exercise (Garber et al. 2011). MET: Metabolic Equivalent of Task, a standard measure of energy expenditure. 1 MET approximately equals energy expended while at rest.

	Relative Intensity	Absolute Intensity
Intensity	Perceived Exertion (RPE)	METs
Very Light	< 9	< 2
Light	9 – 11	2.0 – 2.9
Moderate	12 – 13	3.0 – 5.9
Vigorous	14 – 17	6.0 – 8.7
Near-maximal to maximal	≥ 18	≥ 8.8

Measuring Heart Rate: To collect data on changes in heart rate resulting from gameplay, player heart rates were measured before and after engaging in the game's physical activity. In order to collect measurements, for most studies, we used a Sportline Solo 925 heart rate monitor that could be worn on the wrist and did not require a chest strap component. Heart rate data could be collected using fingertip pulse measurements when participants held their index finger on the device case for several seconds. This allowed for quick, convenient measurements to be taken.

Measuring Energy Expenditure: Study participants wore a BodyMedia CORE armband for the duration of a study session in order to measure energy expenditure during the exercise portion of the procedure. The sensor is able to detect energy expended in metabolic equivalent of task units (METs) with mean error of less than 10% (Berntsen et al., 2010). The BodyMedia's online ActivityManager application allows data collected by the armband to be displayed as a chart of average expended METs, shown below.

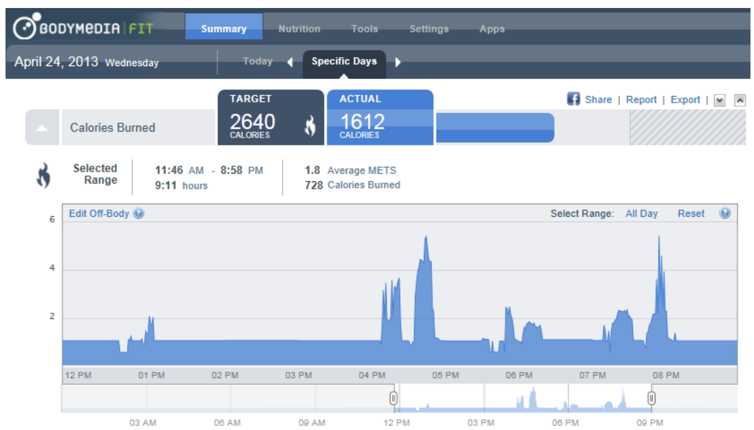


Figure 3.1: BodyMedia's ActivityManager application screenshot (Displaying data from April 24, Washboard, Astrojumper and Legerdemain studies conducted).

Measuring Player-Perceived Exertion: Ratings of perceived exertion (RPE) are another measure that can be used to evaluate exercise intensity. The Borg RPE scale is a 15-category scale, with numbers used to describe levels of perceived exertion intensity ranging from '6' (exertion intensity felt while at rest) to '20' (maximal level of exertion). RPE has a reasonably linear relationship with heart rate and oxygen uptake during aerobic exercise (Borg, 1985; Utter, 2013).

In addition to using the above measures to gain information on the effectiveness of exercise provided by our games, we evaluated the success of the games' dynamic difficulty adjustment systems. To do so, we used observations from our studies and feedback collected from players regarding the game's challenge level. An effective difficulty adjustment system should result in a game that is not too easy or too hard for players to manage, for example, players with a range of exercise habits or different fitness levels should be able to complete the game, and be challenged but not physically over- or underwhelmed.

3.2.1.3 Evaluating the Effectiveness of Game Mechanics

In addition to the above, for some studies we were able to collect movement data from the Kinect, which tracked the player's body during play, and log other data from game software that allowed a post-session examination of players' gameplay choices and performance metrics. Each game had specific goals regarding the types of movements that players would be encouraged to engage in during play, in support of the target form of exercise, and we used game logs and Kinect data to evaluate the extent to which the game mechanics' design actually prompted these movement types, without the players being given extensive instruction before playing.

3.2.2 Evaluating Attractiveness and Attractiveness-Effectiveness Balance

Determining success in reaching exertion type and intensity goals is only one aspect of exergame evaluation: a successful exergame also needs to be engaging and enjoyable to play. A variety of measures were used to determine players' psychological responses to the games. Each study utilized questionnaires and gathered qualitative feedback from players which allowed us to learn which aspects of the game experience players did or did not respond well to, and later studies used questionnaires more specifically targeted at components of the player experience such as flow and mood states.

Survey Questions and Qualitative Feedback: Most survey questions were formatted as Likert scales and asked participants to rate their agreement with various statements relating to their enjoyment of the game experience, the perceived difficulty level of the gameplay and the physical exertion performed during play, and their opinion of how well the game was able to motivate exertion. At the end of each study, participants were also asked to freely respond to questions about their favorite parts of each game and suggestions they had for improvements. Feedback of this type allowed us to learn how successfully game and exercise elements and the difficulty level of presented challenges were balanced. The qualitative data also gave us more information on specific components of the games and ideas for future improvements.

Measuring Mood State: Studies reviewed in section 2 have shown relationships between positive affect and flow, and motivation to engage in an exercise activity. Our later studies used the Positive and Negative Affect Schedule (PANAS, Watson et al., 1988) questionnaire to examine changes in mood state resulting from participation in an exergame. The PANAS is a reliable and valid measure of positive and negative affect (Crawford & Henry, 2004) and consists of two mood scales measuring positive and negative affect, and asks respondents to use a 5-point scale to indicate the extent to which they have felt different emotions within a stated time frame. For our studies, we asked participants to state their feelings at the present moment, and the questionnaire was administered both before and after playing the game.

Measuring Flow Experience: In our final player experience studies, we used the Flow State Scale-2 (FSS-2, Jackson et al., 1992) questionnaire to examine flow states experienced by players engaging in any of the four exergames. Reliability estimates for the FSS-2 ranged from 0.80 to 0.92 in (Jackson et al., 1992) and from 0.76 (acceptable) to 0.90 in a more recent study (Jackson et al., 2008). In order to collect as much information as possible, we used the long form of the scale, consisting of 36 items asking respondents to indicate their level of agreement with various statements relating to nine dimensions of flow: challenge-skill balance, action-awareness merging, clear goals, unambiguous feedback, total concentration on the task at hand, sense of control, loss of self-consciousness, transformation of time, and autotelic (intrinsically rewarding) experience. The FSS-2 was originally developed to measure flow experiences in sport and performance settings and while there is a more general version of the instrument, the version we used was the original, which was recommended for use in a movement-based context (Jackson et al., 1992, 2010). This scale has been used in previous exergame studies, as mentioned by Thin et al. (2011).

3.3 Outline

Following sections will describe each individual game's design and implementation, and detail study procedures and results.

- Section 4 will describe the original Astrojumper game and user study.
- Section 5 will describe Astrojumper-Intervals, the interval training Kinect version of Astrojumper, and the comparison study of the two game versions.
- Section 6 will describe the Legerdemain game, and the results from initial and follow-up studies.

- Section 7 and 8 will describe the design and implementation of the Sweet Harvest and Washboard exergame prototypes, and discuss some player feedback collected during the subsequent player experience studies.
- Section 9 will present the results of the player experience study examining mood states and flow experiences from players of the Astrojumper-Intervals, Legerdemain, Sweet Harvest and Washboard games.
- Section 10 will discuss insights gained into successful exergame design and dynamic difficulty system implementation.

CHAPTER 4: ASTROJUMPER

4.1 Introduction, Goals and Approach

Astrojumper is an aerobic exergame for an immersive virtual reality and upper-body motion tracking platform. In the following sections we will describe the goals for the Astrojumper project and the research questions that were addressed, the game design and platform, the user study that was conducted, and the results from that evaluation (Finkelstein, 2011). We will conclude with a discussion of the project findings, limitations and contributions.

Astrojumper was the first exercise game we developed, and was primarily a proof-of-concept project that enabled us to explore the design and implementation of an exercise game for the CAVE Automatic Virtual Environment (CAVE) virtual reality system. The original purpose behind the project was to design an exercise game that would appeal to children with autism, which guided our choice of platform and game theme. However, the first user study of this game was planned to involve neurotypical participants of a variety of age groups, and we did want the game to be enjoyable and effective for many types of players, so we needed to address several issues in the course of the project. Our immediate goal was to create an enjoyable game that players could interact with through full-body motion, with data from an electromagnetic tracking system used as game input. We experimented with different body movement game mechanics that could be supported with the tracking system, and attempted to design gameplay that was easy to learn and involved intuitive movement, minimizing the amount of instruction needed for new users to begin playing. As we wanted the game to appeal to, and be playable by different types of users, we also needed to address the issue of the game's difficulty level. Sinclair's (2007) dual-flow model of exergame attractiveness and effectiveness was used as a framework for design and evaluation. We wanted to discover players' responses to the novel exercise game on the CAVE platform, and also evaluate the intensity of exercise elicited through gameplay. For our initial study, we hypothesized that Astrojumper would be a fun activity for players of different age groups (both children and adults) as evaluated through qualitative feedback, and that effective exercise could be shown through heart rate increases resulting from gameplay.

4.2 Astrojumper

Figure 4.1: Astrojumper in the CAVE.

Astrojumper is a full-body exertion game developed for the CAVE virtual reality platform, a stereoscopic projection display and a Polhemus Fastrak electromagnetic tracking system that allowed us upper-body motion tracking capability. Astrojumper is set in outer space: throughout the game, planets fly toward the player who must duck, jump or dodge from side to side in order to avoid colliding with them. Four trackers, worn on the head, wrists and torso, provide player position information for the game's collision detection calculations. Periodically throughout the game, a giant UFO flies into view and attacks the player by shooting red laser beams toward the player's head. These lasers can be dodged, and players can make punching or throwing motions to shoot green lasers back at the UFO until it has been defeated. Players earn a base score of one point for each second spent playing, and this base score can be increased by point multipliers earned through hitting gold bonus planets that appear mixed in with the other planets in the game. If players collide with any of the other planets, their score is frozen for two seconds (up to a maximum of 15 seconds with repeated collisions) and any score multiplier they have is eliminated. Collisions with bonus planets that occur while the score is frozen can reduce the amount of time remaining before the player resumes earning points. Otherwise, in addition to earning an increased score multiplier, the player will gain an extra 30 points. Feedback for player actions and game events is an important consideration for exercise games, as with any video game. Astrojumper's heads-up display (HUD) includes the player's score and score multiplier information, as well as a countdown timer that shows how much time is left before the end of the game session. Feedback for other game actions, like planet collisions or earning bonus points, is presented using both visual and audible effects.

4.2.1 Game Progression

In accordance with the ACSM guidelines for exercise, Astrojumper's gameplay includes a warm-up phase during the beginning 15% of the total game time and a cool-down phase during the final 15% of the game. Planets move very slowly at the beginning of the game and gradually speed up throughout the warm-up phase; this allows players to get used to the gameplay if playing for the first time, and steadily increase their pace of movement and heart rate as they progress into the main workout. In the cool-down phase, this process occurs in reverse and the planets slow down, allowing for a gradual decrease in physical effort. The main workout portion of the game takes place between the warm-up and cool-down phases. During the workout, the game uses an automatic difficulty adjustment system to alter the game speed and modify the game's challenge based on the player's performance. The ACSM recommends that moderate-intensity physical exercise be accumulated in sessions lasting at least 10 minutes (Garber et al., 2011), so for our study of this game, participants played Astrojumper for a total of 15 minutes, which included a 2.25-minute warm-up, a 10.5-minute workout that targeted heart rate elevation, and a 2.25-minute cool-down.

4.2.2 Dynamic Difficulty Adjustment

Astrojumper implements a dynamic difficulty adjustment system that monitors a player's performance during a game session and uses the information to automatically and continuously adjust the game's difficulty level during play. This was considered a better approach to the question of game difficulty than, for example, implementing static difficulty options (i.e. "easy," "normal," "hard" as found in many traditional video games) and having players choose a difficulty option before playing, for two main reasons. First, players may not know what to choose. A level of difficulty that is too easy may be temporarily acceptable for a novice player while they learn the rules of the game, but then could quickly become boring and might not challenge the player's physical abilities to the point where effective exercise is achieved. Also, a level of difficulty that is too high could become frustrating, and the player discouraged from continuing. More importantly however, static difficulty levels are not likely to be flexible enough to meet the needs of a wide variety of players at different levels of fitness and comfort with the game system.

The main concept behind Astrojumper's difficulty adjustment system is straightforward. The primary measure of player success used is the percentage of planets that are successfully dodged, and this percentage is calculated once every five seconds. The exact frequency at which difficulty adjustment checks occur can be varied. The developer may consider the trade-off between the amount of player performance data desired (more data will take a longer amount of time to accumulate), and the granularity at which the game is given opportunities to adjust difficulty factors. In Astrojumper, gameplay progresses relatively quickly and sufficient performance data can be collected in a five-second interval to inform the difficulty adjustment system, which uses pre-defined threshold values to decide the player's level of success, and adjusts the challenge level of the game accordingly, as outlined in Figure 4.2. Astrojumper's gameplay difficulty is increased or decreased by altering the speed of the planets as they fly toward the player.

```
/* Calculate every 5 seconds: */

Success_Ratio = Number_of_Dodged_Planets / Total_Number_of_Planets

If Success_Ratio is greater than Threshold_Success_Rate:
    Calculate an increase in game speed based on the difference
    between Success_Ratio and Threshold_Success_Rate, adjusted for
    and bounded by the range of allowable game speeds.

Else if Success_Ratio is less than Threshold_Success_Rate:
    Calculate a decrease in game speed as above.

/* Different threshold values are used for the warm-up and main workout
game portions (to ensure that speed does not increase quickly during the
warm-up). */
```

Figure 4.2: Pseudocode for Astrojumper Difficulty Adjustment

4.3 Study

A user study of Astrojumper was conducted to determine the game's appeal to neurotypical participants of different age groups and backgrounds, and gather feedback for future exergame development. We hypothesized that the game would be able to prompt at least moderate-intensity physical exertion, sufficient to result in a noticeably elevated heart rate, which we measured by asking participants about the exertion intensity they experienced while playing, and by calculating changes in heart rate resulting from play. Our evaluation of Astrojumper involved 30 participants ranging in age from 5 to 50 ($M = 21.17$, $SD = 9.53$). Ten participants were children (ages 5-17) and 20 were adults (ages 18-50). Participants were recruited primarily via word-of-mouth and were not limited to university students. All participants were told the study would require exercise, and that they were not eligible to participate if they had a medical condition that prohibited voluntary physical exertion.

4.3.1 Procedure

We conducted individual participant sessions lasting approximately 45 minutes each. Participants were given an informed consent form to read and sign, and could ask questions about the virtual reality equipment and the study. We explained that we were evaluating how people interacted with an exercise game. Participants' initial, resting heart rate measurements were taken using a HeartMath emWave Desktop heart rate monitor that was attached to the earlobe, left to calibrate for approximately 30 seconds, and then used to obtain the average heart rate over a two-minute period. Participants then took a questionnaire asking about demographic information, activity level, their motivations for exercise, and video game habits. Following this questionnaire, the researcher helped the participant put on a backpack that was used to hold the torso tracker and the wires from all four trackers out of the way. Participants also put on the stereoscopic glasses that allowed them to see the game in 3D, and Astrojumper's start screen was displayed during this time to allow participants to adjust to the 3D stimuli.

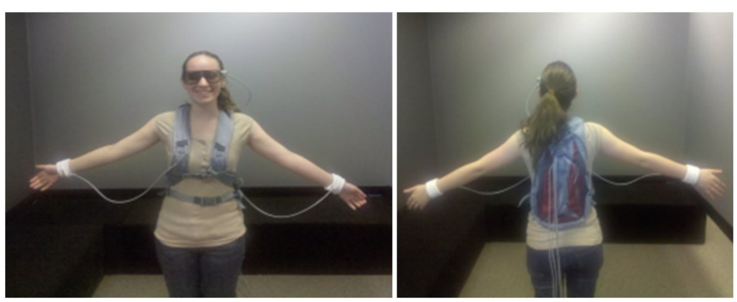


Figure 4.3: Tracker wire setup.

At this time the researcher explained the rules and goals of the game, and answered any questions. The participant then played Astrojumper for a 15-minute session, during which the researcher held the tracker wires several feet behind the participant to ensure they would not trip over them while playing. After the 15-minute play session was completed a post-game heart rate measurement was taken, and a final questionnaire administered which included questions relating to the intensity of the game's workout, motivation, and gameflow experience, along with space for qualitative feedback about the game.

4.3.2 Measures

4.3.2.1 Heart Rate

A HeartMath emWave Desktop heart rate monitor was used to measure a participant's resting heart rate (in beats per minute) before and immediately following game play. Several issues with the heart rate measurements should be noted: because of the cool-down phase included at the end of an Astrojumper session, players' heart rates measured at the end of the game most likely had dropped slightly from maximum levels reached during the main exertion phase. The heart rate monitor used in this study did not allow us to obtain valid readings throughout the game session due to participants' rapid physical movements. Regardless, the exerted heart rate after gameplay still gives us an objective measurement of participants' physiological reactions to the physical activity required to play Astrojumper. In order to use heart rate to evaluate the exertion level of Astrojumper's gameplay, we looked at the rise in heart rate from pre-game to post-game measurements. A significant rise in heart rate would be one indication of effective exertion, while no significant difference would imply either that Astrojumper's gameplay did not require intense exertion or that participants were not sufficiently motivated to engage in physical activity.

4.3.2.2 Workout Intensity, Motivation and Engagement

To gain additional information on workout intensity, adult participants were asked to rate their perceived exertion using a 7-point Likert scale (1 “not at all intense” to 7 “extremely intense”). To measure enjoyment and motivation to play, the final questionnaire included several statements that adult participants rated their level of agreement with using a 7-point Likert scale (1 “strongly disagree” to 7 “strongly agree”); younger participants were given questions with simplified language or images instead of numbers (e.g. asked to choose a happy or sad face) and their responses were not averaged with the others. These included such statements as, “I would rather do game-based exercise over typical exercise,” “I put more effort into my movements than I would have if there wasn’t any virtual simulation,” or “I would exercise more if I could play Astrojumper whenever I wanted.” The ratings from these individual questions were averaged together to calculate a motivation metric. Also to assess Astrojumper’s success as an engaging activity, participants were asked to what extent eight gameflow components from Sweetser et al.’s (2005) model were present in Astrojumper, and to what extent the components should ideally be present in exercise games in general. These ratings used a 5-point scale of importance (1 “not at all,” 2 “somewhat,” 3 “moderately,” 4 “mostly,” 5 “completely”). We compared ratings for Astrojumper to ratings for the “ideal” exercise game to discover the degree to which Astrojumper matched participants’ expectations for an engaging exercise game. Finally, on the post-game questionnaire we asked participants for general comments and qualitative feedback on their favorite and least favorite elements of the game.

4.3.2.3 Video Game and Exercise Habits

The pre-game questionnaire collected participants' basic demographic information, along with information on their video game playing and exercise habits. We asked participants to rate their enjoyment of playing video games using a 7-point Likert scale (higher numbers corresponded to greater enjoyment), and to place themselves in a gaming frequency category ("non-gamer," "casual gamer," "moderate gamer," or "hardcore gamer"). The Godin Leisure-Time Exercise Questionnaire was used to measure how active participants were; this is a short survey that asks how many times per week a person takes part in mild, moderate, or strenuous exercise. Additionally, the included Motives for Physical Activity Measure asked participants to rate different motivations for exercise (interest, competence, fitness, social and appearance) on a 1-5 scale.

4.4 Results

All statistical results reported use a significance value of $\alpha = .05$.

Participants' heart rates were analyzed with a 2x2x2 mixed analysis of variance (ANOVA) test of the between-subjects effects of gender and age (child or adult) and the within-subjects effect of time (resting or post-exertion). Participants' exerted heart rates after completing the game, even following the cool-down phase (M = 106.67, SD = 13.75) were significantly higher than their resting heart rate (M = 77.07, SD = 13.15), $F(1,26) = 72.89$, $p < .01$, $\eta_p^2 = .74$). Overall, the heart rate for males (M = 88.87, SD = 10.72) was slower than females (M = 97.05, SD = 9.94), $F(1, 26) = 5.05$, $p = .03$, $\eta_p^2 = .16$, which is a well-known physiological difference between genders (Finkelstein, 2011, citing Umetani et al., 1998). None of the other main or interaction effects for gender or age were significant. These results indicate that playing Astrojumper resulted in an average heart rate increase of 38% (29.6 beats per minute) regardless of the participant's gender or age.

4.4.1 Analyzing Workout Intensity, Motivation and Engagement

The subjective workout intensity ratings on the 1-7 point scale indicated that participants felt Astrojumper provided a moderate to high level of physical exercise ($M = 5.07$, $SD = 1.44$). Additionally, participants' motivation scores on the 1-7 point scale indicated that Astrojumper successfully motivated them to exercise ($M = 5.69$, $SD = 1.10$). Participants' gameflow evaluation scores of Astrojumper as compared to their "ideal" game were high overall: of a maximum gameflow score of 32 for an ideal game (for eight gameflow components), Astrojumper gameflow scores came within four points of the ideal on average ($M = 28.46$, $SD = 2.62$), indicating that Astrojumper came close to completely fulfilling expectations for the ideal exercise game on a variety of gameflow characteristics.

The relationship between these measures was assessed using Pearson correlation coefficients. There was a significant positive relationship between motivation and workout intensity, $r(30) = +.49$, $p < .01$. Workout intensity and gameflow evaluation were also positively correlated, $r(28) = +.40$, $p = .03$. These results suggest that to design exercise games that provide an effective workout, participants' gameflow expectations and their level of motivation should be considered.

To assess the impact of gender and age (child or adult), 2x2 univariate ANOVAs were each performed on motivation and workout intensity. However, none of the analyses were significant.

4.4.2 Video Game and Exercise Habits

Our participant pool consisted of 7 subjects who considered themselves non-gamers, 15 casual gamers, 5 moderate gamers, and 3 hardcore gamers. For video game enjoyment ratings using the 1-7 scale, most participants indicated they enjoyed playing video games (M = 5.17, SD = 1.15). Responses on the Godin Leisure-Time activity scale indicated that participants tended to engage in moderate levels of exercise (M = 53.97, SD = 31.84), though this varied greatly among participants. The Motives for Physical Activity Measure item rated most important by our participants was fitness (M = 4.19 on a 1-5 point scale, SD = 0.82), followed by interest (M = 3.49, SD = 0.84), appearance (M = 3.33, SD = 1.28), and competence (M = 3.28, SD = 1.05). Social motivations were rated as least important (M = 2.87, SD = 1.23). To assess the potential impact of video game and exercise habits on exercise game design and experience, we computed Pearson correlation coefficients between the subjective ratings of motivation and workout intensity and our measures of video game enjoyment, Godin Leisure-Time activity, and the Motives for Physical Activity. However, none of these factors significantly correlated with the degree of motivation to play Astrojumper or the level of workout experienced by participants.

4.4.3 Qualitative Feedback

We generally received extremely positive feedback from participants, who mentioned a variety of reasons behind their motivation to play Astrojumper. Three of our younger participants said that the game allowed them to pretend they were various superheroes or cartoon characters, with a 12-year-old male participant citing that he enjoyed inventing different “move styles” to change character roles. Two participants mentioned that they most enjoyed the quick thinking and strategy that was required to maximize the score, and an additional four described how much they enjoyed engaging in full-body interaction. Three participants directly compared Astrojumper to the Wii Fit, saying that full-body exercise was much more motivating and effective, one stating it was "much more than the Wii could ever offer." Most participants mentioned specific gameplay aspects of Astrojumper. For example, a 19-year-old male participant wrote:

"My favorite part of Astrojumper was the fact that it didn't really feel like exercise - I wasn't focused on my heart rate or trying to 'push' myself. I just played the game. It wasn't until afterwards it had felt like I had done any exercise."

Additionally, a 22-year-old male mentioned: "I most enjoyed the amount of quick, snap decision movements that were required. It incorporated both top and bottom movements, and this basic sort of game could hone some very sharp coordination skills."

The negative feedback we received was much less varied: out of 30 participants, 17 either left this question blank or wrote that they had no complaints or negative comments. Five participants complained that there were times when they had been penalized for hitting a planet when they felt they were out of its way. This was unavoidable, and was due to inconsistent tracking data that occurred when the electromagnetic trackers were out of range of the emitter. Since the emitter was mounted from the ceiling, this sometimes occurred when participants crouched to the floor to duck under a planet. Three participants said they would have preferred a larger tracking area so they would have some more room to move around, and the other five simply offered suggestions for ways to make the game more fun, such as adding boss fights, additional enemies, or making it easier to beat the UFO. Finally, we received many positive accolades in the free comment section. Some responses included: “it was amazing, it should be a real video game I could play whenever I want,” “I loved all of it, and would recommend it to anybody,” and, “this was one of the best games I've ever played. I actually enjoyed exercise!” Additionally, many participants (over half) requested to play the game a second time, and we received many requests from friends of participants that heard about the game, even after the study was over.

4.5 Discussion

As a proof-of-concept exercise game project, Astrojumper was very successful in that participants responded well to the game, and gameplay resulted in significant heart rate increases. Astrojumper demonstrates a good exergame design in both attractiveness and effectiveness aspects described by Sinclair’s (2007) dual-flow model. Participants in this study were from different age groups, had different gaming and exercise habits, and different motivations for exercising, and responses to Astrojumper were still overwhelmingly positive. Also, Astrojumper demonstrates how a game may be designed to support aerobic activity, described as, “regular, purposeful exercise that involves major muscle groups and is continuous and rhythmic in nature” (Garber et al., 2011) and incorporate ACSM guidelines for exercise session length and structure. The achievement of a successful balance between gameplay attractiveness and exercise effectiveness is further supported by the ability of the game’s difficulty adjustment system to respond to individual players’ performance levels: participant fitness habits varied greatly, but all noted feeling at least somewhat challenged by the gameplay, and none felt the game was too difficult to complete. Overall we felt that the dynamic difficulty system implemented in Astrojumper was effective, and its independence from Astrojumper-specific components and conceptual simplicity mean that extending or modifying it for a different type of aerobic game should be a straightforward process.

From a motivational perspective, it is interesting to note the differences in qualitative comments received from children and adults. Younger participants often mentioned getting "lost" in the fantasy world they imagined around the game, which is consistent with a previous exergame study that found a correlation between children's 'fantasy level' and level of enjoyment (Yannakakis et al., 2006). However, the adults who played Astrojumper more often mentioned being engaged by the challenge, and the skill required to play the game. These differences could have implications for designers wishing to develop exergames that target specific audiences. Also, though, it is possible that the creativity in movement allowed by Astrojumper's gameplay is able to appeal to both preferences: children may gain more enjoyment from being able to move according to their fantasy worlds or characters, and adults are faced with the challenge of quick decision-making and reflex development. While our observations from this project support the attractiveness-effectiveness model and the claim that exergames need fun and engaging gameplay in order to maximize their effectiveness, Sinclair's (2007) work does not discuss how the attractiveness and effectiveness dimensions might overlap, for example as with creative movement as part of both gameplay and exercise, which we found to be a notable part of Astrojumper's success.

It should also be noted that the virtual reality platform used for Astrojumper might have introduced a novelty factor into participants' responses to the game. In section 5 of this paper, we discuss a comparison study between two different versions of the Astrojumper game that use the Microsoft Kinect instead of the CAVE VR system and electromagnetic trackers. In addition to possibly decreasing some of the novelty effect, this change in platform may have had both positive and negative effects on the game's ability to immerse players in their activity. For example, the Kinect does not require players to be physically connected to the game system as did the electromagnetic tracker setup, possibly reducing players' feeling of restriction during play. However, the Kinect implementation of the game did not support stereoscopic projection, and the use of a 2D display instead of a 3D display, and the Kinect game's third-person point of view as opposed to the CAVE version's first-person view, may have reduced the feeling of immersion in the game environment. A future study could examine platform differences and the various ways in which they influence player exergame experiences, and it would also be of value to conduct a closer examination of how long a novelty effect might last, and what elements of an exergame are able to sustain player interest once that effect has passed.

4.6 Conclusion

This section has presented Astrojumper, a virtual reality full-body exercise game; a discussion of the exercise guidelines considered in the game design and the implementation of a dynamic difficulty adjustment system; and the evaluation of both game attractiveness and exercise effectiveness. We were able to gain some understanding of a successful exergame design approach and collect data on how players responded to the game, and how their expectations related to their experience with the game. The positive relationships found between the game experience and willingness to engage in exercise led to our second project: Astrojumper-Intervals was a new version of the Astrojumper exergame in which we were able to successfully demonstrate how both attractiveness and effectiveness aspects could be improved through the incorporation of additional exercise and game design concepts. The design and evaluation of Astrojumper-Intervals are discussed in the following section.

CHAPTER 5: ASTROJUMPER-INTERVALS

5.1 Introduction

Section 4 discussed the design and evaluation of Astrojumper, an immersive virtual reality exercise game. Astrojumper as an exergame was successful in both attractiveness and effectiveness aspects, as measured by qualitative player feedback and a significant increase in heart rate resulting from a 15-minute play session (Finkelstein, 2011). With the release of the Microsoft Kinect, we were able to develop a version of Astrojumper that used the Kinect for player motion tracking instead of the original game's electromagnetic tracking system, taking advantage of the Kinect's more accurate and higher-resolution body tracking abilities.

This section will describe Astrojumper-Intervals, an expanded version of the Astrojumper game. We will discuss our goals and design approach for improving multiple aspects of the original game, the new content and mechanics, and the results from a comparison study of the Kinect version of the original Astrojumper game and Astrojumper-Intervals.

5.2 Goals and Approach

The first Astrojumper study showed positive correlations between the exergame's perceived intensity and motivation to exercise while playing it, and the game's perceived ability to provide a good gameplay experience when evaluated using flow-related characteristics. Such results, along with feedback collected from players during the study, were used to inform the direction of our second exergame project. Astrojumper-Intervals was designed to improve upon the game attractiveness and exercise effectiveness of the original Astrojumper game in two areas. First, we increased the variety of game goals and mechanics in order to improve player enjoyment and motivation. Second, the physical challenge of the game was increased through the inclusion of additional mechanics that targeted specific regions of the body and types of exercise. Our approach to the design of this game was also intended to further investigate how game elements could be combined with established exercise training practice, and to this end we based Astrojumper-Intervals' gameplay progression on an interval training framework.

5.2.1 Interval Training

The gameplay of Astrojumper-Intervals is based upon an interval training schedule. Interval training repeatedly alternates between periods of high-intensity exertion and recovery periods of low-intensity or no exertion. Both aerobic and anaerobic fitness can be improved in a shorter amount of time through interval training than through continuous training, as more work is performed at a higher intensity in that time (Boutcher, 2011; Karp, 2011). Interval training is an effective way for professional athletes to work on enhancing sports performance (Billat, 2001) but is also an option for exercisers who desire changes in their routines to avoid boredom, or who want to improve their fitness level and the efficiency of time spent exercising (Babraj, 2009). Interval training schedules may vary the duration of each interval. In an interval workout, the low-intensity and high-intensity time periods might remain constant (for example, one minute of low-intensity activity followed by one minute of high-intensity activity, and so on), or implement a pyramid structure where a minute of low-intensity activity is interspersed between high-intensity periods that last for 30 seconds, then 45s, 60s, 90s, 60s, 45s, and 30s. Astrojumper-Intervals follows this pyramid schedule, as described below.

5.3 Astrojumper-Intervals

Astrojumper-Intervals was developed for the PC, using the OpenSceneGraph graphics engine and the Microsoft Kinect for full-body tracking, with position and orientation data from the player skeleton detected using the Flexible Action and Articulated Skeleton Toolkit (FAAST) (Suma, 2011).

5.3.1 Game Design

In the Kinect version of the original Astrojumper game (referred to from here on as Astrojumper-Original), planets fly through space toward the player who must move from side to side, jump, or crouch to dodge them. The player earns bonus points and score multipliers by hitting bright gold planets that are mixed in with the obstacle planets. Also, at certain points during the game, a UFO appears and attacks by shooting lasers at the player, who may dodge them and make punching or throwing motions to shoot lasers back at the UFO and attempt to destroy it. Collision with game objects (planets and laser projectiles) is checked using 15 tracked points on the player's body, detected by the Kinect and FAAST software: the head, neck, torso, right and left shoulders, elbows and hands, and right and left hips, knees, and feet. The game is structured to include a beginning warm-up phase, a main exercise phase, and a final cool-down phase in accordance with the ACSM's guidelines for workout stages (ACSM, 2000). During the warm-up phase, planets initially move very slowly and gradually speed up. This is reversed in the final cool-down phase. In the main exercise phase, in order to provide a flexible level of challenge for players of different abilities and fitness levels, the game uses a dynamic difficulty adjustment system. This system changes the speed of planets based on player performance: if a player is doing well, i.e. dodging the majority of planets, the game will gradually speed up to increase the challenge level. If the player is struggling and colliding with more planets, the game will gradually slow down to let the player catch up.

In the interval training version of the game, Astrojumper-Intervals, the planet-dodging gameplay is used as the main activity during the low-intensity exercise periods. In order to support the higher intensity periods and improve upon gameplay variety, Astrojumper-Intervals incorporates three new mini-games. Each of these mini-games focuses on one specific type of exercise or region of the body, and is designed to provide a more intense physical challenge than the planet-dodging game mechanic. Each mini-game also utilizes a slightly modified form of the original difficulty adjustment system, described below, which supports the goal of allowing the mini-games to maintain a higher-intensity activity requirement. The gameplay of these three mini-games is described in the following sections.

5.3.1.1 Space Invaders

In the Space Invaders mini-game, instead of a single UFO appearing to attack the player as in Astrojumper-Original, waves of approaching UFOs appear and the player is able to constantly fire lasers at them by punching rapidly. The player earns points during this mini-game by hitting each UFO with lasers a certain number of times in order to destroy it. If the player fails to destroy UFOs before they reach the player, points are deducted from the player's score. The rapid punching movements focus exertion on the upper body.

Figure 5.1: The Space Invaders Mini-Game.

5.3.1.2 Asteroid Belt

Figure 5.2: The Asteroid Belt Mini-Game.

During the Asteroid Belt mini-game, horizontal rows of asteroids fly toward the player. These rows are positioned so that players must either duck under high rows or jump over low rows, and the positions (high or low) are randomly determined, presenting the player with an unpredictable sequence of jumps and crouching movements. In order for the low asteroid rows to be placed at a visible height and still allow the player to successfully jump over them, this mini-game implements a “super-jump” system, where changes in knee positions are used to detect when the player is jumping, and allows the game to then augment the jump by raising the in-game player skeleton higher than the player is actually able to physically jump; this is primarily a feedback mechanism. This activity targets the lower body, exercising muscle groups in the legs. Successfully avoiding the asteroids will add to the player’s score, and colliding with the asteroids will deduct points.

5.3.1.3 Space Rock Band

Figure 5.3: The Space Rock Band Mini-Game.

The Space Rock Band mini-game is designed to give players a more intense version of the aerobic challenge presented by the planet-dodging mechanic. Inspired by the Rock Band (Harmonix, 2007) game mechanic in which players must correctly hit all of a series of glowing notes to succeed, Space Rock Band sends waves of stars toward the player, whose goal is to hit all of them in succession to play different sound effects and earn bonus points. Stars are positioned in a way that makes players move around the entire play space in both the horizontal and vertical directions, and in patterns that occasionally make players stretch to reach all of them at once. These patterns can be randomized, or specified to form particular shapes, as with one included series of star patterns that players can hit by performing jumping jacks. Points can be earned by successfully hitting stars, and additional points are given for hitting all possible stars.

5.3.1.4 Modified Difficulty Adjustment System

In the original Astrojumper, the difficulty adjustment system gathered data on the percentage of planets successfully dodged by the player, and used threshold values to determine whether to speed up or slow down the pace of gameplay in order to match the level of challenge with the player's current ability (described previously in section 4 on Astrojumper). Astrojumper-Intervals uses the same system during the planet-dodging activity that takes place between higher-intensity mini-game intervals.

The minigame intervals use a very similar system that increases or decreases game difficulty by increasing or decreasing the game's pace. Rows of asteroids, waves of UFOs and groups of stars will approach the player with increasing speed if the player is doing well (successfully jumping over or crouching under rows of asteroids, destroying larger percentages of the number of UFOs, or successfully hitting most of the stars as compared to threshold values); or will decrease their speed if the player is not doing as well. However, the modified mini-game system also takes into account the need to sustain a greater challenge level during higher-intensity exercise periods. This is accomplished by defining a minimal game speed, helping maintain a baseline difficulty level. Each mini-game begins at this minimum difficulty level and remains there for a short time to give players a few seconds to adjust to the new challenge. After this time, player success or failure rates are used to adjust the minigame difficulty, but the difficulty will not decrease below the initial minimum.

5.3.1.5 Game Progression

In Astrojumper-Original, a 15-minute play session includes 3 minutes of warm-up, 9.5 minutes of exercise with four 'UFO battles' occurring throughout, and 2.5 minutes of cool-down. Astrojumper-Intervals follows the same basic sequence, but implements a pyramid interval training pattern during the 9.5-minute workout. For the high-intensity intervals, each mini-game is played twice: 30 seconds of Space Invaders, 45 seconds of Space Rock Band, and 60 seconds of Asteroid Belt, followed by a second 60 seconds of Asteroid Belt, 45 seconds of Space Rock Band, and 30 seconds of Space Invaders. Each of these intervals is followed by one minute of dodging planets, for the lower-intensity exertion period.

5.4 Study

In order to compare the intensity of the exercise provided by the Astrojumper-Original and Astrojumper-Intervals games as well as players' enjoyment of the gameplay, we conducted a within-subjects study where participants played each game for 15 minutes, in a randomly assigned order, for a total 30 minutes of play. The table below includes descriptive data on the 34 participants: the range, average, and standard deviation for age, height, weight, and Body Mass Index (BMI).

Table 5.1: Participant age, height, weight and BMI.

Gender	Age (years)	Height (in.)	Weight (lbs.)	BMI
Male N = 23	Range: 18 – 28 M = 20.83 SD = 2.84	Range: 60 – 73 M = 69.65 SD = 3.14	Range: 120 – 230 M = 166.74 SD = 33.38	Range: 18.47 – 33.9 M = 24.17 SD = 4.52
Female N = 11	Range: 18 – 37 M = 23.55 SD = 6.73	Range: 60 – 68 M = 63.64 SD = 3.14	Range: 92 – 170 M = 134.64 SD = 24.93	Range: 17.97 – 31.17 M = 23.37 SD = 4.21

The Center for Disease Control and Prevention estimates Body Mass Index (BMI) as $\left(\frac{\text{Weight}}{\text{Height}^2}\right) * 703$, with results categorized as following: underweight (below 18.5), normal (18.5 – 24.9), overweight (25.0 – 29.9) and obese (30.0 and above). Although in cases where a person has high muscle mass the BMI measurement will not be accurate, it still may be used as a general heuristic for body fat percentage (CDC, www.cdc.gov/healthyweight/index.html). The average BMI for both male and female participants in this study fell within the normal range, and the average self-rating of lifestyle activity level was 4.74 on a 7-point scale (1 = "Not active at all", 7 = "Extremely active"), indicating that the participants were, on average, reasonably healthy and active. Sixteen of 34 participants indicated they had previous experience with interval training. The average participant self-rating of video gaming frequency (hours per week spent playing games) was 1.36 (1 on the scale corresponded to low frequency, 1-3 hrs/week; and 2 corresponded to medium frequency, 4-6 hrs/week) and participants generally agreed with the statement “I think video games are fun,” with an average rating of 5.85 on a 7-point Likert scale (1 = “Strongly disagree”, 7 = “Strongly agree”).

5.4.1 Procedure

Participants were invited into the research lab for individual 60-minute study sessions. An initial demographic survey was administered, and the participant was given a BodyMedia armband (described in section 3.2.1.2) to place around their upper left arm, which would measure energy expenditure in METs (metabolic equivalent of task) during play. The armband required several seconds to begin detecting physiological input, after which it emitted an audible beep to signal the end of calibration. We measured resting heart rate using a Sportline Solo 925 heart rate monitor, by taking the lower of a measurement when the participant arrived at the lab and a second measurement after they had been sitting for several minutes while filling out the pre-game survey. Then the participant played 15 minutes of either Astrojumper-Original or Astrojumper-Intervals (assigned randomly as the participant entered the lab). A second heart rate measurement was taken immediately upon completion of the first 15 minutes of gameplay. The player was then asked to sit and fill out a survey asking about their experience with the game, including a subjective rating of perceived exertion (RPE), and this time spent with the survey allowed players to rest and their heart rate to slow. After completing the survey participants were given additional time to rest if they wished before playing 15 minutes of the second game version (whichever version they did not play first). Heart rate was similarly measured before and after the second game session, and an identical short survey, asking about the participant’s experience with the second game, was given.

Finally participants filled out a short questionnaire asking them to compare the two games, describe preferences, and include any additional comments.

5.5 Results

5.5.1 Evaluation of Exercise Effectiveness

5.5.1.1 Measures

Three physiological measures were used to evaluate the level of exertion intensity elicited by each game. A Sportline Solo 925 heart rate monitor was used to take fingertip pulse heart rate measurements (beats per minute) before and after playing each game. A BodyMedia armband was used to collect energy expenditure data during each play session. Following each game, an abbreviated version of the Borg (1970) Rating of Perceived Exertion (RPE) scale was used to evaluate participants' perceived level of exertion as 'None' (0), 'Light' (1), 'Moderate' (2), 'Hard' (3), or 'Very Hard' (4).

5.5.1.2 Results

Perceived exertion ratings did not significantly differ ($p = 0.07$) between game versions: Astrojumper-Original ($M = 2.03$, $SD = 0.83$, Range = 0 to 3) and Astrojumper-Intervals ($M = 2.27$, $SD = 0.72$, Range = 1 to 4). However, average energy expenditure was significantly greater ($p = 0.042$) during Astrojumper-Intervals than Astrojumper-Original: Astrojumper-Original METs ($M = 4.745$, $SD = 1.57$); Astrojumper-Intervals METs ($M = 5.03$, $SD = 1.8$). Further, average METs for both games were significantly greater than a METs value of 4 (Astrojumper-Original: $p = 0.03$; Astrojumper-Intervals: $p = 0.003$), which is useful to note as the CDC defines moderate intensity energy expenditure as 3-6 METs (provided examples of activities at this level include dancing, swimming, or biking on a level surface) (http://www.cdc.gov/nccdphp/dnpa/physical/pdf/PA_Intensity_table_2_1.pdf). Also, a 2x2 mixed analysis of variance (ANOVA) testing the effects of gender and time (change in heart rate as a result of play) showed a significant change in heart rate from pre-game to post-game measurements for both games ($p = 0.000$), with Astrojumper-Intervals resulting in a significantly ($p = 0.018$) greater increase in heart ratecompared with Astrojumper-Original: Astrojumper-Original pre-game HR ($M = 90.42$) and post-game HR ($M = 113.55$); Astrojumper-Intervals pre-game HR ($M = 87.29$) and post-game HR ($M = 119.15$).

5.5.1.3 Implications for Exercise Effectiveness

These results indicate that the interval training version of Astrojumper succeeds in eliciting greater exertion than the original game version through a 15-minute play session, and it is interesting to note that despite this result, there was no significant difference in rating of perceived exertion. It is possible that differences in game play, and their effect on player engagement, could influence a subjective exertion rating: this would be a positive conclusion, as one of the benefits of immersive play is the ability to distract from any discomfort caused by exertion. However, as discussed later, we cannot necessarily draw that conclusion from this study.

Additionally, it should be noted that post-game heart rate measurements most likely do not reflect peak HR achieved by playing either game, as the post-game measurements were taken after each game’s ending cool-down phase. In total, 29 of 33 players (87.9%) reached 50% or above of their maximum heart rate (MHR); 15 of 33 (45.5%) reached 60% or above of their MHR; and 5 of 33 (15.2%) reached 70% or above of their MHR (the CDC roughly calculates MHR as 220 – age). The target heart rate “zones” necessary to improve cardiovascular fitness vary by individual fitness level, for example, the ACSM recommends that a sedentary person work out at 55-65% of their MHR, while more fit individuals need to work at 65-80% of MHR to see improvement. A more thorough evaluation of the effectiveness of these custom exergames could form a clearer picture of peak HR reached, and the length of time that increased heart rates are maintained, in order to benefit future exergame design. Similarly, measuring continuous heart rate during a game session could give us more information regarding levels of exertion during the mini-games as compared with the planet-dodging gameplay, in order to identify to what extent the mini-games prompted more intense exercise. Also, no association was found between players’ final scores and the amount of effort expended as measured by HR or METs. Improvement in this area would allow better estimates of a game’s exercise effectiveness, and be especially useful when offering accurate performance or progress feedback to players.

5.5.2 Evaluation of Game Attractiveness

5.5.2.1 Measures

Primary measures of game enjoyment and motivation to engage in physical activity were 7-point Likert scale items on the post-game surveys given to participants after each play session, and on the questionnaire given at the end of the study. We asked players to rate how much fun they had while playing, how easy or difficult it was to understand and play the game, and what they thought of the game’s challenge level. We also asked which game they preferred, if they would recommend the game to friends, and gathered qualitative feedback on opinions of the game, the experience, and whether they thought video games could be effective exercise tools.

5.5.2.2 Results

Of seven items included on the post-game surveys where participants rated agreement with statements such as, “I found Astrojumper to be less stimulating than my usual exercise routines,” and “I felt Astrojumper gave me a good challenge,” no significant differences were found between the Astrojumper-Original and Astrojumper-Intervals responses. However, responses to both games were generally positive. On the 7-point Likert scale (1 = “strongly disagree”, 7 = “strongly agree”), average agreement with the statement “I found Astrojumper to be a fun experience” was M = 5.35 for Astrojumper-Original and M = 5.36 for Astrojumper-Intervals; the statement “I felt Astrojumper gave me a good challenge” was M = 5.18 for Astrojumper-Original and M = 5.35 for Astrojumper-Intervals. More interesting results were found in the final game comparison questionnaire, in which 27 of 34 respondents (79.4%) stated a preference for Astrojumper-Intervals. The reasons given for this preference centered around the greater variety of both gameplay and types of movements used to play, which kept players more entertained and focused through the entirety of the workout, presented a better challenge, and felt more interactive. Four of the remaining participants preferred Astrojumper-Original for its level of challenge, and the final three did not prefer one game over the other. It is also notable that 79.4% of respondents said they would be willing to recommend Astrojumper (their preferred game version) to friends: a response that could indicate the game’s potential to motivate increased adaptation and possibly adherence (repeated play), both of which would be desirable for an effective exergame.

5.6 Discussion

The original Astrojumper game primarily supported aerobic activity, which occurs as players dodge from side to side to avoid planets. Astrojumper-Intervals demonstrates an expanded set of game mechanics that support increased targeting of upper- and lower-body-specific exercises, implemented through the Space Invaders and Asteroid Belt mini-games. Like the original Astrojumper game, Astrojumper-Intervals includes warm-up and cool-down phases before and after the main workout session. It also shows how the workout schedule may be further modified to increase both enjoyment and energy expenditure among players, by using an interval training framework that alternates between high- and low-intensity exertion. The dynamic difficulty adjustment system first used in the original Astrojumper game continued to work well at balancing the challenge level of the game and was also successfully applied to the new mini-games. The comparison study presented here offers an interesting look at how an interval training framework may be translated into game design, and how variety of gameplay positively affects players' enjoyment and exertion levels.

Study participants stated a wide variety of motivations behind their exercise habits. Many described exercise as an activity done to maintain health, increase positive attitude, and decrease stress; other reasons included participation on sports teams, losing weight, or wanting to improve appearance. One said it helped motivate them to quit smoking, and another cited simple enjoyment. Given this diversity, it is encouraging that the majority of participants had such a positive response to Astrojumper. A few valuable insights into exergame design can also be taken from this study. The structure of Astrojumper-Intervals demonstrates how to incorporate a traditional exercise program into a video game for the purpose of increasing the physical challenge and potential physiological benefit of the game. We can also see how increased game variety affects player enjoyment, and recognize that in an exercise game, variety can come not only from game goals and mechanics, but also from types of physical movements that the player can engage in to play the game.

Despite the positive response to Astrojumper, participants' comments on whether or not video games in general can be effective and motivational exercise tools reflect awareness that the state of currently available exergames is behind that of traditional video games in terms of gameplay and utilization of technological capabilities, and even farther behind traditional established exercise techniques in the ability to provide really effective workouts. Opinion statements from the majority of participants seemed to follow a pattern in that they were willing to believe exercise games could be enjoyable and effective, but only for certain populations or under certain circumstances. Specifically, gamers, inactive people, and children were mentioned as being the groups most likely to enjoy and benefit from exergames. The following quotes illustrate some of these perceptions: "I think that [exergaming] is beneficial to encourage gamers to actually get involved in physical activities. Sitting around eating and pushing buttons… isn't healthy, at least this way they enjoy what they're doing and get a positive effect from it," or, "I think [exergames] are a great idea! As popular as gaming consoles are and as lazy as people are this is a great way to get lazy folks to exercise" and, "I think with improvement of the kinect/wii this could be a huge increase in exercise activity. There are too many glitches right now for it to be effective enough to get people into a fun work out routine."

Observations from this study also suggest several potential directions for future research. Significant differences were found between heart rate changes and energy expenditure between the two game versions, but not in players' ratings of perceived exertion. To gain more clarity in this area, a larger participant group, or a sample of less active players, along with use of the 6-20 point RPE scale could be beneficial. However, a potentially interesting future study might examine the effect that engaging gameplay has on perceived exertion ratings. A more enjoyable game might lead players to feel like they are engaging in less physical exertion, or a less enjoyable game might lead to players feeling a higher amount of exertion, even if the level of intensity is actually the same. Also, while data collected throughout this study did show a statistically significant difference in exercise intensity between Astrojumper-Original and Astrojumper-Intervals, a long-term comparison study could investigate the practical significance of the difference in exertion elicited by the two games, and the effects of differences in game enjoyment on adherence. Future work could also examine the Astrojumper-Intervals game, specifically the difficulty adjustment system and mini-game mechanics, in more detail in order to discover ways to further increase the intensity of the game's challenge.

5.7 Conclusion

Astrojumper-Intervals demonstrates an exergame implementation of an interval training schedule that benefits both player enjoyment and exertion intensity. The project offers further insights into game design applications of exercise type and intensity considerations, and also demonstrates a difficulty adjustment system that supports periods of increased challenge for interval training.

The Astrojumper and Astrojumper-Intervals games presented in this and the previous section have focused for the most part on aerobic exercise, and dynamic difficulty adjustment systems that use conceptually simple measures of player success to modify game difficulty through increased or decreased pacing. The following sections will present exergames that target alternative forms of exercise and aspects of difficulty adjustment systems specific to these different activity types.

CHAPTER 6: LEGERDEMAIN

6.1 Introduction

Many existing exercise games focus on aerobic forms of activity as defined by the ACSM: "regular, purposeful exercise that involves major muscle groups and is continuous and rhythmic in nature." However, other forms of activity are also recommended for balanced exercise prescriptions and health: strength training, or resistance exercises with every major muscle group; flexibility exercises that stretch major muscle-tendon units; or neuromotor training that exercises motor skills (e.g. coordination, agility) or multifaceted activities (e.g. yoga) (Garber et al., 2011).

Game mechanics that support these other forms of exercise have not been extensively explored. Existing work that deals with exergames or technology-supported physical activity intended for these non-aerobic exercises falls mainly in the areas of rehabilitation research or sensors to detect accuracy of form while working out. Kiili and Merilampi developed a smartphone game prototype where two teams of players perform squats as frequently as possible to win a tug-of-war contest (Kiili & Merilampi, 2010). This is a form of movement that could be used for lower-body muscular strength or endurance training, but their work was for the most part focused on exploring types of movement detectable by the smartphone platform instead of enabling different forms of exercise usable in a balanced workout program. Other work relating to technology-supported anaerobic exercise has not focused on games, instead looking at other ways that platforms or devices may be used to assist exercisers. For example, sensors have been used to detect the accuracy of exercisers' weight-lifting movements for the purpose of giving feedback to help them perform the exercises correctly (Velloso et al., 2011).

Legerdemain is a wizard duel-themed exertion game for the Microsoft Kinect, with game mechanics that allow for a combination of aerobic activity and anaerobic exercise in the form of upper-body strength training for muscular endurance. This section describes the design of Legerdemain, and the results from a user study evaluating psychological and physiological responses to the game. We also performed an initial exploration of logged game data and skeleton joint positional data from the Kinect to discover the forms of physical activity that were most rewarded by the game, in order to determine their alignment with the forms of activity intended by the game's design. A comparison of the backgrounds and play styles of novice players who were more and less successful while playing showed several interesting trends and feedback from this first study resulted in several improvements to the game. Those changes will also be described here, along with several results from a second user study.

6.2 Goals and Approach

One of our primary goals for this project was to experiment with game mechanics for anaerobic exertion. The ACSM's guidelines state the need to engage in different forms of activity in a balanced workout program, however, many exercise games support only aerobic exertion. Legerdemain's gameplay is intended to support some aerobic activity, but also light- to moderate-intensity resistance training (mostly upper-body, but with some lower-body activity) as a mix of exercise types can result in a more efficient workout. To this end, the main game mechanic allows the player to 'cast spells' by moving their hands in patterns displayed on the screen (see Figure 6.1). For the user studies, in order to provide resistance and in place of custom controllers, participants wore weighted wristbands while playing. The game includes a mechanic wherein the amount of weight used by a player can be entered into the game, and increased weight translates to increased spell casting power (e.g. spells will cause more damage, or offer more protection); outside of the study environment, this type of mechanic might encourage players to use increasingly heavier weights during gameplay for more effective strength development. We hypothesized that at least moderate-intensity exertion would be elicited through gameplay but considered it a possibility that players would perceive the exertion level of the game to be lighter, especially stronger players whose movements would be less affected by the amount of weight carried on each wrist, as the maximum weight we allowed for the study was 20 lbs. This limitation was imposed partially because of equipment availability, but more so because we started every participant with very light weights that could gradually increase throughout the game session, in order to avoid injury or delayed onset muscle soreness.

Legerdemain also experiments with a difficulty adjustment system that is more flexible than that used in the Astrojumper games. The game consists of four levels, each with a slightly different goal regarding the type and intensity of exercise to support. Each level also confronts the player with an opponent that will behave differently, in accordance with those exercise goals. This results in the need to adjust difficulty in ways other than simply changing the speed of the game. Also since players are able to adopt different strategies during gameplay, choosing one type of action to use as a measure of player success, as in Astrojumper, is no longer adequate.

For the first user study, we used measures similar to those used in the Astrojumper game comparison study in order to evaluate game attractiveness and effectiveness, but also wanted to conduct some post-game analysis using data logged from the game, along with player movement data from the Kinect, in order to gain some insight into differences in movement or play strategies among more or less successful, or more or less fit, players. We believed this could help us gain a more detailed picture of which parts of the game were successful, and which were not, and evaluate their alignment with the exercise types targeted by the project.

6.3 Legerdemain

Legerdemain is a first-person wizard duel game developed for the PC and Microsoft Kinect using the OpenSceneGraph graphics engine and FAAST to stream skeleton joint positions from the Kinect to the game software (Suma, 2011). In Legerdemain, players attempt to defeat a series of different opponents by casting spells. The game's mechanics are designed to provide a combination of aerobic activity and light to moderate resistance exercise targeted at maintaining or improving muscular endurance, although the game allows players some flexibility to choose, based on preference, which form of activity to engage in most often. Resistance training mechanics let the player cast spells by moving their hands in specific patterns while wearing weighted wristbands, and in order to provide incentive for players to use the wristbands, the amount of weight used was entered into the game and factored into their spell casting power. For example, spells cast by a player using heavier weights could do more damage to the in-game opponent, or take effect more quickly or for a longer amount of time. Reaching all parts of displayed spell patterns requires movement across the entire play space: players may need to reach above their head or down to the ground, or move side-to-side to complete each spell. Other aerobic activity may occur as players duck under or dodge around projectile spells cast at them by the game opponents.

Figure 6.1: Screenshot from Legerdemain's second game level. Spell options are displayed by circles along the top, and a progress bar is displayed at the bottom of the screen. Selecting a spell causes the spell pattern to appear in the central area of the screen. (3D models used in the game were borrowed from the 3D Warehouse at http://sketchup.google.com/3dwarehouse/)

6.3.1 Resistance Training

The resistance or strength training activity is centered in the spell casting game mechanic. During the game studies, players wore weighted wrist bands to provide the necessary resistance as they cast spells by moving their hands in patterns to match those displayed on the screen (see Figure 6.2). Traditional weightlifting exercises like pulldowns, curls or extensions use a variety of movement types in order to work different muscle groups and the game's spell patterns were chosen to encourage similar variety, but were also modified to require movement across a larger physical space while playing.

Vertical movement was emphasized to bring about the exertion that comes from lifting weight, and the movements needed to hit all parts of a spell pattern could have players leaning or crouching down to bring their hands near the ground, or reaching up above their heads. The result is that aspects of the game's workout are more functional, involving movements that do not replicate traditional exercises exactly, but are closer to those of everyday activities.

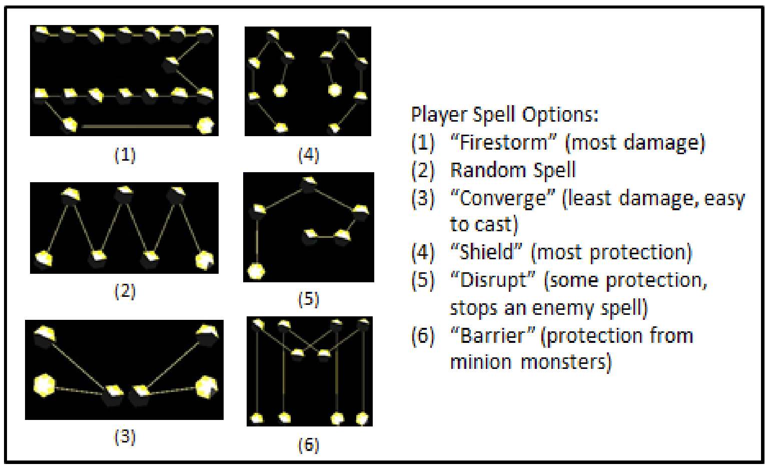


Figure 6.2: Spell patterns available in Legerdemain.

6.3.2 Aerobic Activity

During the game, players may utilize different tactics to protect themselves from the spells cast at them by the game opponents. They may focus on the strength training aspect of the game by using heavier weights to increase their spell casting power so that defensive spells offer greater protection. Alternatively, many of the spells cast by opponents result in projectiles that the player can dodge or duck under. A player may choose to use lighter weights, which will reduce their power but could allow them to use greater speed, as quickly moving from side to side will let them avoid taking damage from a number of these projectiles and reduce the need to cast strong defensive spells. This would result in more aerobic exercise taking place.

6.3.3 Game Progression

Legerdemain consists of four levels that are each five minutes in length. Players earn points based on the amount of time that passes in the game and on how well they are performing relative to the game opponent. As can be seen in Figure 6.1, a slider bar at the bottom of the screen provides a display of the player's degree of success: each time the player damages the opponent, the slider moves to the left, and if the opponent is able to damage the player the slider moves to the right. As the player moves the slider farther to the left, the number of points earned per second is increased. Additional points are given based on the player's status once the five minutes have been completed: a level can end with the player's victory or defeat, or the player's advantage or disadvantage if the ending difference between the player's and the opponent's overall success is not greater than a defined threshold. Accumulated points are displayed at the end of each level, and a screen at the end of the game shows the player's final score and a list of previous high scores. It is possible for a level to end before its five minutes have passed. If the player is able to damage the opponent enough to bring the slider into the leftmost section of the bar and keep it there for 45 seconds, the level will end with a victory for the player.

The first game level presents an easier challenge and is designed to act both as a warm-up period, and as a tutorial wherein the player can learn the effect of the various spells available. The opponent in this level is able to cast basic offensive and defensive spells and is not especially fast or powerful. The second level continues the warm-up phase of Legerdemain but at a more intense level of exertion. This level's opponents are fast and able to throw a variety of projectile spells that the player must shield against or dodge; the focus of this level is on aerobic movement meant to increase the player's heart rate through quick movement, in preparation for later levels that will shift concentration to strength exercise. In contrast to the second level, the third level's opponent is much slower but also more powerful and able to take a large amount of damage. This level encourages the player to use more weight, in order to increase their spell casting power and become able to cause enough damage within the five-minute timeframe to defeat the opponent. Level four moves closer to a balance between the targeted exertion in levels 2 and 3: the opponent is slightly faster than the level three opponent, and is able to cast "minion summoning" spells that cause groups of small enemies to appear and attack the player. A possible strategy for the player here is to use a similar amount of weight as encouraged by the third level but also work at moving to cast spells more quickly, in order to successfully defend against the groups of small enemies.

6.3.4 Difficulty Adjustment System

In our previous Astrojumper games, a player's performance could be measured by calculating the percentage of planets that were successfully dodged within a certain amount of time, and the game's difficulty could be adjusted accordingly by increasing or decreasing the speed at which the planets moved toward the player. A similar method cannot be used so easily in Legerdemain, due to the different strategic choices a player is able to make, and the need to support different opponent behaviors. For example, some opponents cast projectile spells that the player can choose to dodge, or the player may instead cast a defensive spell to protect themselves from damage and not bother to dodge enemy spells at all. Or, adjusting the game's difficulty by changing the speed of enemy spell casting may make sense for the opponent in the game's second level, where speed is the main element of difficulty, but not for the opponent in the game's third level where spell power is the more important characteristic. Initially, we considered collecting a large amount of information on multiple aspects of player performance, including spell casting speed and current power, the percentage of spells successfully dodged or shielded against, the amount of damage dealt to the game opponent during defined time intervals, and so on, and weighting or interpreting these values differently based on individual opponents' desired behaviors in order to adjust difficulty. We found that in practice, however, this approach was overly complex and difficult to balance to the point where the game was sufficiently responsive to player actions.

Upon completion of a first user study, described below, we implemented several changes to the game including a modified difficulty adjustment system. In the new system, we measured the player's degree of success by considering the amount of damage caused by the player to the opponent, relative to the damage caused by the opponent to the player. This is represented by the slider bar visible at the bottom of the game screen. This bar was divided into eight sections, and a set of difficulty-related values (for example: opponent spell casting speed and power, or the probability that each of the opponent's spells could be used) were defined corresponding to each of these sections. Then, the game's difficulty was increased or decreased according to these value sets each time the slider moved into a new section on the left or right. This method was straightforward to implement and different difficulty value sets could be quickly defined and modified, and could support the game opponents' individual behaviors. It also avoided the need for complex systems able to guess a player's chosen play style and did not require performance data to be collected over a period of time before it could be responded to. Ultimately it became somewhat similar to Astrojumper's system in that a relatively simple measure of the player's performance could be found and used, although Legerdemain's implementation was more flexible in terms of what that measure could be, and how it could be used. We found during a second user study, also described below, that this system was more responsive and more forgiving toward new players, with clear improvements observed in participants' experiences with the game.

6.4 User Study #1

We gathered both qualitative and quantitative data from 29 participants, recruited through advertising the study in UNC Charlotte's departments of computer science and kinesiology, in order to assess psychological and physiological responses to the game. Our goals were to gather feedback from players about the experimental game mechanics in Legerdemain, to see which elements were more and less successful, and also to evaluate the types of physical activity elicited through gameplay, in order to determine Legerdemain's ability to provide an effective mixture of aerobic and anaerobic exercise. Table 6.1 summarizes several characteristics of our participant group. The Body Mass Index (BMI), while not accurate in all cases such as for people with high muscle mass, still may be used as a general heuristic for body fat percentage, and is calculated by the Center for Disease Control and Prevention as $\left(\frac{\text{Weight}}{\text{Height}^2}\right) * 703$, with results placed in the following categories: underweight (below 18.5), normal (18.5 – 24.9), overweight (25.0 – 29.9) and obese (30.0 and above) (CDC, 2011).

Table 6.1: Participant characteristics, study #1.

Gender	Age (years)	Body Mass Index (BMI)
Male (N = 20)	M = 24.15, SD = 5.38	M = 24.67, SD = 3.65
Female (N = 9)	M = 20.89, SD = 1.76	M = 25.61, SD = 6.34

In a pre-game survey, participants were asked to respond to the question, "How active do you consider yourself?" using a 7-point scale (1 = "Not active at all", 7 = "Extremely active"), and the average response was 4.3 (SD = 1.34), showing a reasonably active participant group. The survey also asked about the frequency with which participants engaged in flexibility, aerobic or anaerobic exercise, with average responses indicating that each type of activity was performed at least a few times per month up to once per week, with aerobic activity the most frequently done (M = 3.76, SD = 1.02), followed by anaerobic activities such as weight training (M = 3.41, SD = 1.45) and flexibility exercises (M = 3.07, SD = 1.28) (on a 5-point scale, where 1 = "A few times a year or less", 2 = "About once a month", 3 = "A few times a month," and 4 = "About once a week" and 5 = "A few times a week or more"). Participants were also asked their opinions of video games and amount of time spent playing games; the average agreement with the statement "I enjoy playing video games" rated on a 7-point scale (1 = "I do not enjoy playing video games", 7 = "I love playing video games") was 4.79 (SD = 1.84). Average time spent playing games for the participant group was 2.32 (SD = 1.44) on a 5-point scale (scale points corresponded to 1 = "0 hours per week", 2 = "1-3 hours", 3 = "4-6 hours", 4 = "7-9 hours", and 5 = "10+ hours"; a response of 2.32 indicates that on average, participants spent a little more than 1-3 hours per week playing video games).

6.4.1 Participant Feedback

On a post-game survey, we asked players for their comments and suggestions on the overall game experience and difficulty level, and if they thought it could be used to motivate exercise. Players' responses were varied, ranging from "Loved it, I'd buy it!" to "Make it easier to win every once in a while so that we can feel good about winning," and "I think there should be better graphics and clarity of moves to keep an adult engaged in it." Several players achieved at least a partial flow experience, indicated by comments saying that the "20 minutes went away in seconds," and that they were able to get into "a groove" after playing enough to get used to the movements. Overall, we found that reactions to the game were generally positive, and that players liked the idea behind the game and thought it could be used to motivate exercise. However, from participant comments and our own observations, we noted several improvements that needed to be made to the interface and game difficulty and feedback systems in order to improve the player experience.

6.4.2 Exercise Evaluation

In addition to collecting qualitative feedback from players, we also evaluated the game's ability to provide the intended form of exercise, that is, a mix of aerobic activity and strength training at a light to moderate level of intensity. During the study, participants played each of the four levels of Legerdemain for an approximate total of 20 minutes of gameplay. For the first level each participant was asked to wear wrist weights totaling 3 lbs. (1.5 lbs on each wrist) and during the second level, weights totaling 5 lbs. For levels three and four, however, participants were given the choice of what amount of weight to use, from 0 to 20 total lbs. To evaluate exercise intensity, the BodyMedia armband sensor was used to collect data on players' energy expenditure levels in METs (Metabolic Equivalent of Task units), where 1 MET is approximately the amount of energy expended while at rest, and moderate-intensity activity falls within the 3.0 – 6.0 METs range (Garber et al., 2011). After each game level, we also asked players to rate their perceived level of exertion on the Borg RPE 6-20 point scale (6 = no exertion, 20 = maximal exertion). Table 6.2 summarizes average METs and RPE for each of the four game levels, along with the average amount of weight used for each level.

Table 6.2: Average weight, RPE and METs for each game level.

Level	Total Weight (lbs)	RPE	METs
1	M = 3, SD = 0	M = 10.28, SD = 2.05	M = 3.48, SD = 0.77
2	M = 4.93, SD = 0.37	M = 12.22, SD = 2.2	M = 3.84, SD = 0.83
3	M = 7.45, SD = 3.82	M = 13.79, SD = 1.88	M = 3.97, SD = 0.75
4	M = 10.1, SD = 6.81	M = 14.76, SD = 2.89	M = 3.5, SD = 0.83

Average METs fell within the 3.0 – 6.0 range, indicating moderate-level intensity, while perceived exertion ratings correspond with this result, as the overall average rating is 12.76, and an RPE of 12-13 ("somewhat hard") indicates exertion within the moderate range recommended for aerobic activity and resistance training (Garber et al., 2011). We also see the average amount of weight used increasing in levels 3 and 4, perhaps indicating that the promise of increased spell casting power was sufficient motivation for players to try using heavier weights. We did observe that the heavier (above a total of 10 lbs) available weight options were simply too awkward for some players to wear around their wrists or arms while playing which, although some were still willing to attempt to use them, led them to ultimately select a lighter option with which to play.

6.4.3 Factors in Game Success

As a second approach to evaluating the psychological and physiological responses players had to the game, we divided participants into two groups by calculating the range of overall game scores, finding the median of that range, and separating participants into Group 0 (N = 19), the less successful group whose scores fell below that center point, and Group 1 (N = 10), the more successful group whose scores were above the center point. An exploration of differences between players who were less and more successful with the game allowed us to determine if the more successful players had certain characteristics, or were utilizing a particular form of exertion that worked well.

First, it is interesting to note that no significant differences in the general rating of activity level or other fitness-related player characteristics, as measured by the pre-game survey, were found between groups. However, a significant difference was found in the reported amount of time spent playing video games ($p = 0.03$, Group 0 $M = 1.89$, $SD = 1.18$; Group 1 $M = 3.1$, $SD = 1.6$; on the 5-point scale described previously). The ideas used in Legerdemain are common in traditional game design, such as the concepts of spells with different offensive and defensive effects, and attempting to find a strategy that will match and defeat an opponent, and so it is likely that a person with more gaming experience will more easily understand and be able to use those ideas in learning how to play a new game. It is beneficial to a player's game experience for their strategic choices to have an effect on the outcome of a game, but ideally for an exergame, increased physical effort should also lead to increased success with the game. While almost no significant differences between average perceived exertion rating and energy expenditure were found between the groups, the more successful group's ratings of perceived exertion (RPE) and metabolic equivalents (METs) were generally higher (see Table 6.3).

Table 6.3: RPE and METs for Group 0 and Group 1, for levels 1-4.

Level	RPE	METs
1	Group 0 (M = 10.11, SD = 1.85) Group 1(M = 10.6, SD = 2.46)	Group 0 (M = 3.26, SD = 0.75) Group 1 (M = 3.91, SD = 0.64)
2	Group 0 (M = 12.05, SD = 1.87) Group 1 (M = 12.55, SD = 2.81)	Group 0 (M = 3.67, SD = 0.79) Group 1 (M = 4.18, SD = 0.85)
3	Group 0 (M = 13.47, SD = 1.71) Group 1 (M = 14.4, SD = 2.12)	Group 0 (M = 3.69, SD = 0.62) Group 1 (M = 4.5, SD = 0.7)
4	Group 0 (M = 14.47, SD = 3.26) Group 1 (M = 15.3, SD = 2.06)	Group 0 (M = 3.43, SD = 0.69) Group 1 (M = 3.63, SD = 1.08)

We should also take note of other differences in the choices and gameplay of the more successful group: they seemed to choose speed over power, as on average they used less weight in levels three and four (Level 3: Group 0 M = 7.79, SD = 3.95 total lbs; Group 1 M = 6.8, SD = 3.68 total lbs; Level 4: Group 0 M = 10.26; SD = 6.56 total lbs; Group 1 M = 9.8, SD = 7.63 total lbs), and their average time between spells was about 3.6 seconds faster than the less successful group (Group 0 M = 10.12, SD = 6.18 seconds; Group 1 M = 6.5, SD = 2.14 seconds). The number of spells Group 1 players were able to cast throughout the game was significantly higher than the number of spells cast by Group 0 players ($p = 0.015$, Group 0 M = 97.47, SD = 24.89 spells; Group 1 M = 122.4, SD = 23.71 spells). Additionally, the average time spent casting any individual spell was shorter for Group 1 than Group 0.

6.4.3.1 Comparing Player Movement

There are previous studies that have compared novices and experts performing various physical activities, in order to find differences in exertion levels and in how movements are performed. Results from these comparisons can be used to discover important variables in the development of expertise and inform instructors' educational methods (Lythe et al., 2000; Temprado et al., 1997). Other work has also used movement tracking data from a Kinect to evaluate movement quality, for example, in comparing rehabilitation exercises as they are performed by patients with a correct exercise form in order to help patients achieve better accuracy of motion, or comparing dancers' performances of a set of choreography to the performances of expert dancers, also in order to provide feedback (Liutkus et al., 2012; Pedro et al., 2012; Stone & Skubic, 2011). These applications need to be able to accurately detect movements and poses in order to effectively compare them with an "ideal" or correct movement. In exergames such as Legerdemain, there is not necessarily a single, correct form of movement to use in accomplishing any game task, although a game system could compare the movements of individual players across different game sessions and attempt to find indications of progress or improvement on which to base feedback given to the player. For the present exploratory analysis, we attempted to compare different movement factors, specifically amount and range of motion, between the more and less successful player groups.

The skeleton joint positions tracked by the Kinect throughout each game session were collected and filtered using an exponential smoothing filter as described in (Azimi), adequate in that latency was not a concern for post-game data analysis and that this filtering pass was in addition to the smoothing made available by the FAAST software (Suma et al., 2011). In order to gain an estimate of the amount of movement taking place during play, distances traveled by tracked points for the torso, hip and hand joints were calculated. An estimate for range of motion was taken by looking at average minimum and maximum values reached. No significant differences in the amount of movement for any joint were found between groups 0 and 1, although average amounts of movement for the less successful group, Group 0, were higher than the average amounts of movement performed by Group 1. Figure 6.3 displays these average amounts of movement, calculated for each 30-second interval during the 20-minute game period.

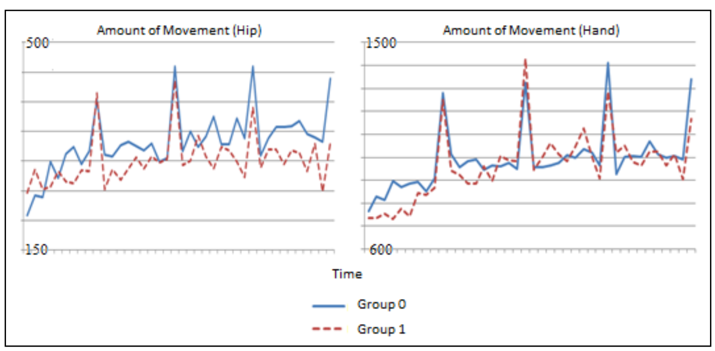


Figure 6.3: Amount of movement (distance traveled) for hip and hand joints, comparison of Group 0 and Group 1 players.

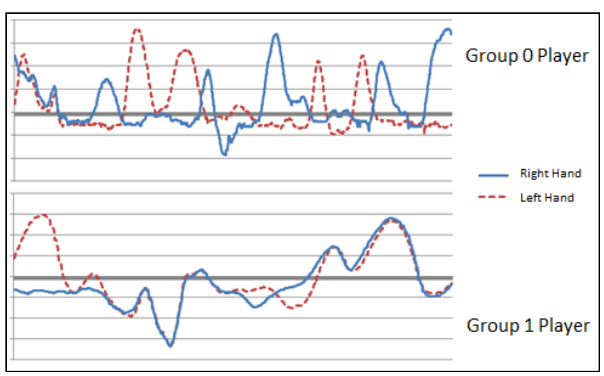


Figure 6.4: Hand positions while casting the "Shield" spell, comparison of Group 0 and Group 1 players.

Although Group 0 players tend to display more movement overall we know, as previously stated, that the Group 1 players cast more spells in less time, so it is possible that the extra movement from the Group 0 players is caused by imprecision when attempting to select spells or connect with the elements in the spell patterns. This is also suggested by the graphs in Figure 6.4 of left and right hand movements for two players, one from each group, while casting the “Shield” spell.

These results seem to indicate that Legerdemain rewards players who move with speed and precision more highly than it does players who move more slowly, even if the slower players are using heavier weights and have increased spell power. While the exercise provided through gameplay does support both aerobic and anaerobic elements to some extent, and the results from the RPE and energy expenditure measures also place Legerdemain’s exertion in the desired moderate-intensity range, future versions of the game should work to improve the balance between exercise types, and allow players with different movement and play style preferences to be equally successful.

6.4.3.2 Comparison of Novice and Expert Players

The primary differences found between the more and less successful groups seemed to be that the more successful players had more experience with video games, and were able to cast spells with more speed and precision than the other players. Average exertion levels as measured by METs data were also slightly higher. Intuitively, these factors (familiarity with the game, speed and precision) would be found to greater extent in expert players, those with more experience with the game and more time spent playing; for curiosity’s sake we may compare the amount of movement, speed and precision of our pilot study participants, who are novice players, with data collected during an expert player's (one of the game's developers) session.

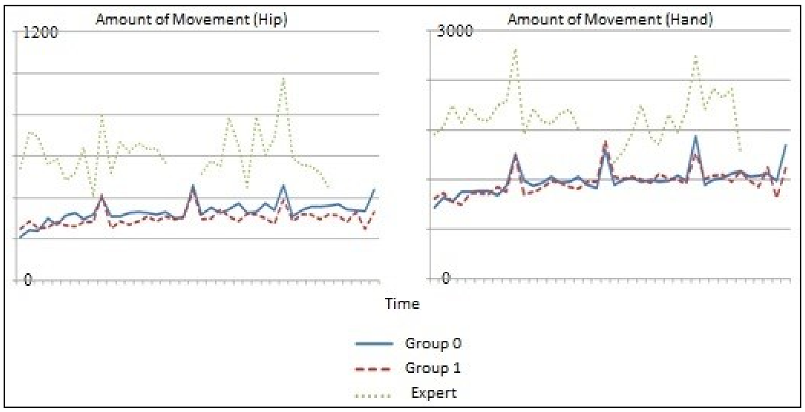
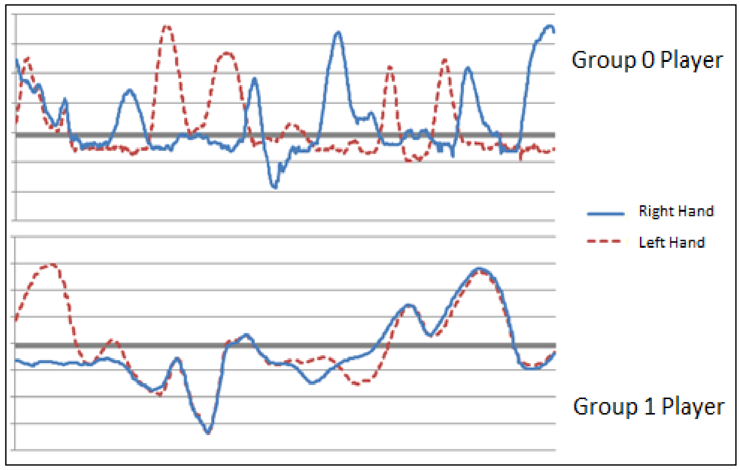


Figure 6.5: Amount of movement for hip and hand joints, comparison of novice and expert players.

Figure 6.5 shows the same data presented in Figure 6.3 but with the addition of hip and hand joint movement amounts from the expert player session, showing much greater amounts of movement from the expert player. Figure 6.6 shows the expert player's left and right hand positions while casting the "Shield" spell, in contrast to the novice players' hand positions during the same spell, shown in Figure 6.4.

Also, as might be expected, the expert player casts a greater number of spells throughout the game, and the time needed to cast individual spells and the time taken between spells is also shorter for the expert player (see Table 6.4).



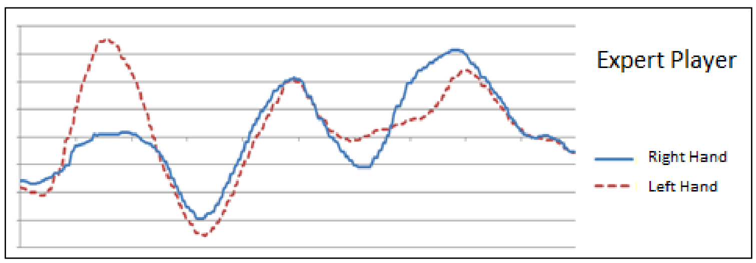


Figure 6.6. Hand positions while casting the "Shield" spell (expert player) in comparison to hand positions while casting the same spell for Group 0 and Group 1 players.

Table 6.4: Comparison of Group 0, Group 1 and expert players.

Player	Total Spells	Average Time Between Spells
Group 0	97.5	10.12 seconds
Group 1	122.4	6.5 seconds
Expert	187	3 seconds

The information we have gained from an exploration of the data logged by the game and from the Kinect as it tracks the player’s skeleton suggests that these data are able to reveal important differences about novice and expert players, even before more sophisticated methods of analysis are applied. Future work could utilize different analysis techniques to discover other features of the data that can be used both to give players feedback about their level of performance and effort during play, and as input to in-game systems able to dynamically adjust the game's challenge level to better balance player skill or fitness. We have seen that familiarity with the game, and greater success during play, seem to positively affect immersion and effort. Differences were found between the participant groups in their psychological reactions to the game: for example, a pre-game and post-game Positive and Negative Affect Schedule (PANAS) measure was used to gain an indication of player mood before and after playing; research has shown that if an exerciser feels good after completing a workout routine, he or she is more likely to engage in that workout again (Soundarapandian et al., 2010). No significant differences were found between the pre- and post-game PANAS measures for the overall participant group, but an increase in positive affect after playing the game was found by the more successful group ($p = 0.049$, Group 0 positive affect decreased by 1.74 points; Group 1 positive affect increased by 3.0 points). This result provides some additional evidence in support of the need for an exergame to balance the level of challenge it presents with players' skill levels, as well as successfully display clear goal information and feedback, as discussed in gameflow theory. Further, it leads to the question of whether players are best motivated by facing a challenge or by winning a game. Future work in this area could discover some interesting implications for how exergames should be balanced or what outcomes game sessions should result in, and how player motivation differs among individuals with different goals, and how it changes with time.

6.5 User Study #2

Following the first user study, we implemented several changes to Legerdemain in order to improve the player experience, focusing on observed and player-stated difficulties with the game's goals and feedback for actions. In addition to modifying the difficulty adjustment system as described above in section 6.3.4, we included an improved tutorial section preceding the first game level, which allowed players the opportunity to experiment with more of the main game mechanics. We also improved several of the game's feedback mechanisms, perhaps most importantly those related to showing players the effects of their spell casting and the results of using different amounts of weight while playing, and those related to showing players where to move if they wanted to dodge an enemy spell. This version of Legerdemain was used in a second user study on player experience, along with the other exergames included in this dissertation. Several of the results from that study will be discussed later in section 9 and compared to the other games, but here we will discuss some of the player responses to the improved version of Legerdemain.

In the second user study, 19 participants played three levels of Legerdemain for an approximate total time of 15 minutes (this change was made to bring the duration of a Legerdemain play session closer to that of an Astrojumper play session, in order to better compare them in the player experience study). Players were given the same weighted wristband options as in the first study, with the only change being the removal of the heaviest, 10-lb. wristband options, which as we observed previously were difficult to play with. Table 6.5 displays some descriptive characteristics of the study participants.

Table 6.5: Participant characteristics, study #2.

Gender	Age (years)	Body Mass Index (BMI)
Male (N = 14)	M = 24.14, SD = 5.97	M = 27.2, SD = 4.09
Female (N = 5)	M = 21, SD = 1.73	M = 28.03, SD = 8.1

Participants self-rated the activity level of their lifestyle an average of 4.17 (SD = 1.76) on the same 7-point scale used in the previous study (1 = “Not active at all”, 7 = “Extremely active”), which was similar to the previous study’s participant group average of 4.3. The average amount of time spent playing video games each week was 2.26 (SD = 1.15) (2 = “1-3 hours” and 3 = “4-6 hours”), also similar to the first study’s group average of 2.32.

Our changes to the game did make it physically easier. Players’ ratings of perceived exertion on the Borg 6-20 point scale were similar in both studies (Study #1 M = 12.76; Study #2 M = 12.55) but energy expenditure differed (Study #1 M = 3.7 METs; Study #2 M = 2.7 METs) despite similar amounts of weight used by players in both studies for each level (Study 1: M = 3 lbs., M = 4.93, M = 7.45; Study #2 M = 3, M = 5.37, M = 7.44 for levels 1, 2 and 3 respectively). However, unlike the first study, the second study did show a significant increase in positive affect (PA) and a decrease in negative affect (NA) for all players (change in PA: $p = 0.036$, M = 2.78, SD = 5.35; change in NA: $p = 0.001$, M = -1.32, SD = 1.42). Likewise, comments left by players on the post-game survey were clearly more positive than in the study using the first version of Legerdemain. Of the 28 participants in the first study who responded to the question, “What did you like or not like about the game? Any comments or suggestions?” 23 of 28 (82%) mentioned things they did not like or thought should be improved, with 11 of 28 (39%) saying that they did not understand what was going on in different parts of the game. Of the 20 participants responding to the same question after playing the second version of Legerdemain, however, only 5 of 20 (25%) talked about what they disliked, with 2 of 20 (10%) saying that they did not understand some of what was happening in the game. This was a very positive outcome and demonstrated the benefits of designing for game flow.

6.6 Conclusion

Legerdemain provides an example approach to the design of an exergame with mechanics that support both aerobic and resistance training at a light to moderate intensity level, with a variable-length game session progressing from an easier warm-up level through following levels of increasing difficulty, in support of recommendations for exercise published by the ACSM. To an extent, the gameplay also is able to accommodate play style preferences: a player who wishes to focus on aerobic exercise may do so, and the use of less weight will necessitate faster movements in order to defeat the more powerful opponents. Likewise, a player wanting to focus on resistance training may use more weight, and the resulting decrease in speed will be balanced by increased spell casting power. The study utilizes measures not often applied to the evaluation of psychological and physiological aspects of exergames. As previously mentioned, future work could apply other data mining techniques to the information gained from the Kinect as it tracks player movements and to additional information about player actions logged by game software, in order to learn about the most important features of these data and use them to give players accurate feedback on their performance or progress, or to adjust gameplay based on players' skills, fitness levels or preferences. The exploration of new game mechanics that support multiple types of exertion, and of techniques used to evaluate the success of new exergames, will lead to further understanding of how exergames may most effectively support and promote physical activity. Likewise, user studies of Legerdemain provided an interesting look into how player background may affect at least a first-time play experience, as it seemed participants who played traditional video games more often were better able to quickly understand game ideas and rules, and could put more focus on the physical movements needed to play, resulting in a better overall experience. The second user study also affirmed the importance of clear goals and feedback, showing their impact on a player's experience and the results from the comparison study of the Astrojumper games suggest that once these aspects of the game's design are successfully implemented, the game's physical difficulty can be increased without negative impact on the play experience. We also believe that a game like Legerdemain could leverage social interaction in a multiplayer mode to greatly increase engagement, a potential area for future experimentation.

Legerdemain was the first game in which we experimented with mechanics meant to support a non-aerobic form of exercise, and the following sections will describe two game prototypes built around additional exercise types: section 8 will describe Washboard, which focuses on a short, intense core workout involving sit-ups, and section 7 will describe Sweet Harvest, another short game which aims to provide dynamic warm-up activities.

CHAPTER 7: SWEET HARVEST

7.1 Introduction

Sweet Harvest is an exercise game prototype that implements new mechanics, a difficulty adjustment system, and other game elements that encourage upper and lower body stretching, and sections of dynamic warm-up activity focused on general movement to increase heart rate. The game can be played in short sessions and is intended for use as a warm-up game, with the potential to be developed further in the future and used as a game for improving players' flexibility. This section will describe the goals of the Sweet Harvest game, its design and level progression, and several results from a user study of the game.

7.2 Goals and Approach

Warming up the body before exercising can reduce the risk of musculoskeletal injury, can increase the effectiveness of flexibility exercise, and can enhance cardiorespiratory or resistance exercise (Garber et al., 2011). Sweet Harvest's gameplay, to be a successful warm-up activity, should start slowly and gradually stretch major muscle groups and increase heart rate. The purpose of this project was to allow us to explore new game mechanics that ideally lead players to stretch their arms and legs and gradually increase their heart rate, and experiment with a difficulty adjustment system that could adapt the game for individual players with different levels of flexibility. Without needing to restrict players to very specific poses, as the main focus of the game was on light movement and stretching, we still put in place mechanics to stop players from moving through stretches too quickly or overly straining muscles.

We hypothesized that the gameplay of Sweet Harvest would be able to noticeably elevate player heart rates and be rated as light-intensity activity by players on the Borg 6-20 point rating of perceived exertion (RPE) scale. In the user study, we also measured player mood before and after the game using the Positive and Negative Affect Schedule (PANAS) and further evaluated players' experience using the Flow State Scale-2 (FSS-2) and qualitative feedback. Some of the results from this user study will be described below, and some in section 9 where the player experience study and comparisons between our exergames will be discussed.

7.3 Sweet Harvest

Sweet Harvest is comprised of a series of activities that increase slightly in difficulty each time they repeat throughout a play session. Three of the activities are different types of stretches: in two of these, apples and bananas appear in a line on the screen, either at shoulder height where players are then prompted to use alternating arms and reach across the body to collect the fruit, or at knee height, where players step to one side and bend their knee in a side lunge to collect fruit. In the third, fruit falls on both sides of the screen and players reach both arms out to the side to catch as many as they can. Each time any of these activities are repeated, the game's difficulty adjustment system causes fruits to appear slightly farther away from the body, increasing the distance the player needs to stretch to reach them. If a short amount of time passes during which the player is missing fruit, the distance at which it appears will begin decreasing slowly, to prevent it from becoming impossible to reach. In addition, for each stretch, the player must keep their hands or knees in position for a certain amount of time to collect the fruit, for example, the fruit farthest away for the single arm or knee stretches must be held for at least six seconds before it can be collected in order to finish the stretch. In addition to the stretches, a fourth activity involves a swarm of ants moving toward the player, who holds a fruit basket in their hands during this stage and must move or jump around in order to kick the ants away with their feet before the ants reach the basket. This activity adds variety to the gameplay and is intended to encourage more movement and increase players' heart rates.

Figure 7.1: Screenshots showing the different activities in Sweet Harvest. Top left: players reach an arm across their body to collect fruit. Top right: players stretch both arms out to the sides to catch falling fruit. Bottom left: players collect fruit with their knees while performing side lunges. Bottom right: players can jump around or kick out to squish swarming ants.

At the beginning of the game, Sweet Harvest uses data from the Kinect to calculate the player's height, as well as arm and leg lengths, and uses that information to generate the initial positions where fruits will appear. The game also utilizes other mechanisms to encourage actual stretching. For example, players must keep their feet inside the bounds displayed at the bottom of the screen, and are not allowed to collect any fruit if they step out of bounds. This prevents players from simply moving from side to side to get closer to fruit that appears farther away from them. Throughout the stretching activities, a swarm of bees is visible flying across the top of the screen. If the player moves too quickly while collecting fruit, the bees will fly down toward the fruit, and if the player continues moving quickly the bees will steal the fruit and the player will lose points; this is intended to encourage slower, more deliberate stretching motions.

7.4 User Study

Thirty-one participants played the Sweet Harvest prototype for approximately 5-8 minutes each. Players' heart rates were measured before and after playing. Players wore a BodyMedia armband to measure energy expended. Surveys before and after the game collected demographic and other background information and feedback on the game, along with data on before and after mood states from the Positive and Negative Affect Schedule (PANAS). Data on players' flow experience was also collected using the Flow State Scale-2 measure, but this will be discussed later in section 9. Table 7.1 shows several characteristics of the user study participant group.

Table 7.1: Sweet Harvest user study participant characteristics.

Gender	Age (years)	Body Mass Index (BMI)
Male (N = 27)	M = 24.04, SD = 5.57	M = 26.98, SD = 6.2
Female (N = 4)	M = 23.75, SD = 4.43	M = 24.73, SD = 3.82

Participants' average BMI fell within the normal (18.5 – 24.9) and overweight (25.0 – 29.9) categories, and the average lifestyle activity rating for all participants was 3.8 (SD = 1.56) on a 7-point scale (1 = "Not active at all", 7 = "Extremely active"). The average amount of time spent playing video games per week was close to 4-6 hours (M = 2.71, SD = 1.27 on a 5-point scale where 2 = "1-3 hours per week" and 3 = "4-6 hours per week"). 9 of 31 (29%) participants reported engaging in flexibility exercise about once a week or more, and 13 of 31 (42%) reported engaging in aerobic and anaerobic exercise about once a week or more. None of the participants had played Sweet Harvest before their study session.

After playing, participant ratings of the perceived exertion of the game averaged 10.16 (SD = 2.05), between very light and light on the Borg RPE scale. Average energy expenditure was 2.0 METs (SD = 0.55), which is less than 3.0 METs and so is consistent with that RPE. Playing Sweet Harvest did result in a slight increase in heart rate (p = 0.00, M = 19.32, SD = 18.43 bpm). These results were expected as the physical challenge level of the game was very low. This may be adequate for the beginning of a warm-up activity, however, a future version of the game meant to improve flexibility could benefit from the inclusion of more light-intensity aerobic activity, resulting in a higher heart rate increase, followed by stretches of more variety and intensity.

Pre- and post-game data from the PANAS were compared within-subjects to discover any change in mood that might have been caused by gameplay, where ideally, a fun game experience could result in an improved mood. While no significant change in positive affect was seen (p = 0.47, pre-game PA M = 31.16; post-game PA M = 31.97), a decrease in negative affect was present (p = 0.00, pre-game NA M = 14.89; post-game NA M = 11.9).

At the end of the study we collected feedback from players on what they did or did not like about the game. Quite a few respondents said they liked the way the game looked, calling it cute, fun and colorful, although at least one participant thought the style was better suited for younger children. Many said the game had a good interface and instructions that made it easy to tell what to do in the game, with the exception of the ant-stomping activity: the majority of participants had some trouble figuring out what to do during these sections. As seen in Figure 7.1 above the only instruction displayed on the screen during the ant sections read, “Use feet to squish ants!” and as we have learned previously, exergame players are not always able to focus on displayed text. Also the ants move fairly quickly toward the player, so the player may not have enough time to figure out what to do the first time this activity occurs in the game; these considerations could be used to improve Sweet Harvest in the future. The other main issue players encountered was some inconsistency in the Kinect’s detection of their movements; many players had no problems but occasionally the Kinect would fail to detect the player, making the game difficult to control.

7.5 Conclusion

The results and observations from our user study showed Sweet Harvest to be a fairly solid prototype, with gameplay that led to movements of the intended type and intensity. Future work could address some of the issues mentioned by players, and also improve the variety of activities available in the game, as well as increase the intensity to the point where the game is usable as a tool for flexibility development.

Sweet Harvest is a unique exergame in that its gameplay focuses specifically on warm-up activities, and we have used it to demonstrate mechanisms that are able to encourage players to move in certain ways and engage in different types of stretches while remaining focused on the play, rather than the exercise, aspects of the experience. We have also shown a difficulty adjustment system that supports a different form of exertion and that needs to take different factors into account, like a player's physical characteristics such as height and reach, than do the difficulty adjustment systems implemented for Astrojumper and Legerdemain. The following section will describe Washboard, a second exergame prototype that also demonstrates support for a different, more intense form of anaerobic exertion.

CHAPTER 8: WASHBOARD

8.1 Introduction

Washboard Gut Killer, or “Washboard,” is a prototype exergame designed specifically as a core muscle workout using various forms of sit-up exercises. Existing exergames generally do not focus on anaerobic, or strength-focused activities, so Washboard was developed to provide one example of how this type of exercise might be supported through a Kinect exergame. Here we will describe our goals for the project, the game design, and several results from a user study of the game.

8.2 Goals and Approach

Supporting anaerobic exertion with a Kinect exergame is not as straightforward as building a game meant for an aerobic workout because of the type of effort involved. Specifically, strength training requires resistance of some sort. Traditionally this can be provided through the use of weights or other equipment, and some exercises use body weight as the source of resistance. However, the Kinect seems most accurate at detecting movement when the player is standing and facing the camera straight on, and this posture does not lend itself to the performance of many body weight resistance exercises. Astrojumper’s asteroids mini-game involved crouching and jumping, and Legerdemain’s user study included the use of weighted wristbands, both of which do cause players to somewhat exert different muscle groups. However with Washboard we wanted to use sit-ups as an effective and more traditional form of anaerobic exertion. This allowed us to experiment with different Kinect set-ups, game elements, and game mechanics that could make even intense exertion fun.

A single play session of Washboard lasts for a maximum of five minutes, and was intended to provide a vigorous core muscle group workout through sit-up exercises. We hypothesized that players would rate their perceived level of exertion at 13 or higher on the Borg RPE scale, corresponding to a perceived intensity of at least “somewhat hard,” but made no predictions for energy expenditure levels or heart rate increases as guidelines for those measures for anaerobic activity are not as clearly stated in published work as are those for aerobic activity. Players, depending on their level of fitness, were not necessarily expected to be able to complete all five minutes of the game successfully and we were interested in observing how many participants during a user study would choose to complete the workout.

8.3 Washboard

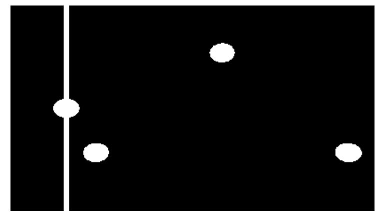
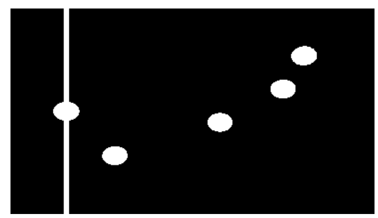
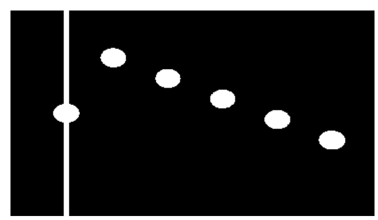
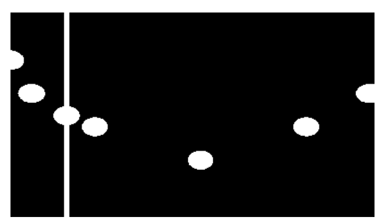
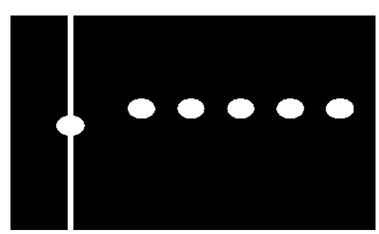
Figure 8.1: Screenshot of Washboard game.

In Washboard the player does sit-ups to control the position of a floating spiky creature, seen in Figure 8.1 above, on the left side of the screen. For our study, the Kinect was positioned above the player in such a way as to be able to detect the player's head throughout the up and down motions of a sit-up, and if the player was sitting up fully the creature was at the top of the screen, and at the bottom of the screen if the player was fully reclined. The goal of the game is to earn points by moving the creature to collide with the balloons that move across the screen from right to left, with the optional, additional goal of avoiding the diamonds that also move across the screen. Colliding with diamonds damages the creature's spikes and takes away lives, displayed in the upper-right corner of the HUD, and lives remaining at the end of the game earn bonus points for the player; running out of lives does not end the game. The game lasts for a total of five minutes. The gameplay and goals are straightforward, but different forms of sit-up exercises that improve the variety of gameplay are prompted by altering the patterns of balloons that appear on screen.

The progression of exercises in the game as defined by the patterns of balloons that appear includes two repetitions of the following sequences in the order shown in Table 8.1

Washboard's difficulty adjustment system looks at the number of balloons that a player collides with as a measure of player performance, and alters game speed to change the difficulty of the game. Unlike the Astrojumper games, however, slowing the pace of this game does not always decrease the difficulty: if balloons move across the screen more slowly it would give the player more time to get in position to hit them, but could also mean that a player would have to hold a strenuous position longer in order to hit balloons that are moving more slowly across the screen. Generally, increasing the game speed (to a limited extent) actually decreases the game difficulty. Also, if players successfully hit all of the balloons in a particular set four times in a row, one iteration of a

Table 8.1: Different forms of sit-up exercises in Washboard.

Set Duration	Description	Screenshot
30 seconds	Rhythmic intervals, or normal sit-ups.	
30 seconds	Accelerating ascensions: beginning from a fully reclined position, players sit up slowly at first and increase their speed the closer they come to an upright position.	
30 seconds	Slow descent: players begin from an upright position and slowly recline.	
30 seconds	Horseshoe stunts: beginning from a mostly-upright position, players descend to a mostly-reclined position and then rise again, to hit balloons that appear in a horseshoe-shaped pattern.	
30 seconds	Core holding: horizontal lines of balloons cross the screen; the player holds a position halfway between sitting up and lying down long enough to hit all balloons.	

random set (randomly positioned balloons) will appear to provide momentary variation and challenge, but the game will return to the planned set progression following the random set.

8.4 User Study

We conducted a user study of Washboard to determine the prototype's success in providing a good sit-ups workout and a fun experience to players. Participants were invited to the lab for a 30-minute session, during which they played Washboard for at most 5 minutes and filled out pre- and post-game surveys that collected demographic and background information on their exercise and video gaming habits, along with feedback on the game experience. We also administered the Positive and Negative Affect Schedule (PANAS) questionnaire before and after to measure any changes in mood perhaps resulting from gameplay. Participants' heart rates were measured before and after playing, and they also wore the BodyMedia armband sensor to detect energy expenditure.

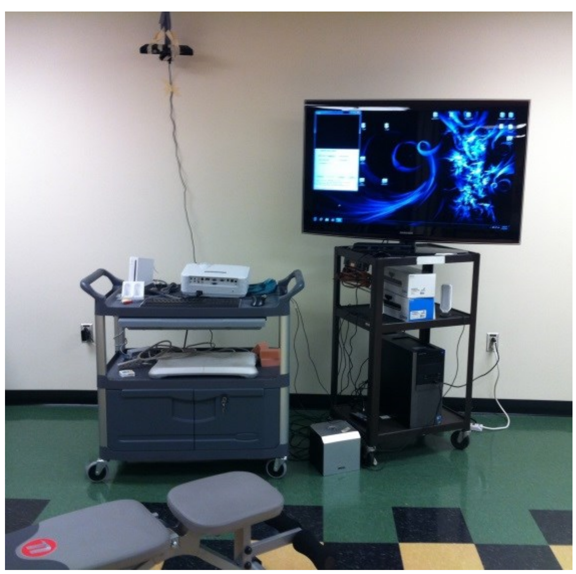


Figure 8.2: Lab setup for the Washboard study.

Our user study had 28 participants, and Table 8.2 shows their average age and Body Mass Index (BMI). The average BMI for both males and females fell into the overweight (25.0 – 29.9) category, and participants self-rated their lifestyle activity levels an average of 4.61 (SD = 1.83) on a 7-point scale (1 = "Not active at all", 7 = "Extremely active"). 18 of 28 (64%) of participants reported engaging in aerobic exercise about once a week or more, and 14 of 28 (50%) in anaerobic exercise.

Table 8.2: Washboard user study participant characteristics.

Gender	Age (years)	Body Mass Index (BMI)
Male (N = 21)	M = 23.1, SD = 6.08	M = 26.02, SD = 6.99
Female (N = 7)	M = 24.14, SD = 5.93	M = 25.8, SD = 4.39

Participants reported spending an average of a little over 1-3 hours per week playing video games (M = 2.27, SD = 1.27 on a 5-point scale where 2 = "1-3 hours per week" and 3 = "4-6 hours per week").

The average rating of perceived exertion for the game was 13.3 (SD = 3.02) on the Borg RPE scale, corresponding to exertion that is "somewhat hard" and matching our hypothesis, although responses were varied, with 5 participants rating the exertion level at 11 ("light") or below, and 10 participants rating it at 15 ("hard") or above. Average energy expenditure was 1.98 METs (SD = 0.39), and playing Washboard did result in a heart rate increase (p = 0.00, M = 20.07, SD = 16.69 bpm).

Results from the PANAS mood state questionnaire showed both a significant increase in positive affect (PA) and decrease in negative affect (NA), indicative of a good experience (PA: p = 0.025, M = 2.09, SD = 4.56; NA: p = 0.00, M = -3.22, SD = 3.19).

At the beginning of the study all participants were reminded that if they wished to stop playing the game they could do so at any time without penalty, but all of the participants completed the entire 5-minute sit-ups workout despite its difficulty, which is a very positive observation. Comments from participants, when asked what they liked or disliked about the game, were similarly very positive. The only real problem encountered by some players was inaccuracy in how the Kinect detected their position, leading to difficulty controlling the position of the spiky creature in the game. This was unfortunate, and we had worked to position the Kinect and filter its data in such a way as to minimize this issue, but could not overcome it completely because of the suboptimal camera angle and differences in player body types. An additional criticism noted that occasionally the diamonds would cross over the balloons on their way across the screen, making the balloons difficult to hit. However, the clear majority of respondents said that the game was fun and gave them a really good workout. Some noted that being able to see the high score motivated them to work harder, and we did observe that some participants who knew others who had played the game asked about their scores in comparison to the others' scores.

8.5 Conclusion

Published exercise guidelines state the need to include a combination of different exercise types in a balanced, effective fitness program. Washboard demonstrates support for anaerobic exercise in the form of a short, intense sit-ups workout that targets core muscle development. Its difficulty adjustment system is similar to that of Astrojumper, as player performance is measured by calculating the percentage of objects (balloons) the player successfully hits, and game difficulty is changed by increasing or decreasing the objects' speed, although the particular form of exercise used by Washboard means that increasing object speed does not always increase game difficulty.

Overall, the response to Washboard was very positive despite the difficulty of the workout it presented and the issues with the Kinect. This project was interesting in that we were able to build a game around a traditional form of exercise and smoothly incorporate game elements to make it an engaging and motivating activity. Washboard used a much more traditional form of exertion for its game mechanic than any of our other exergames, and is also the most physically difficult, which allows some interesting comparisons to be made with our other games; we will discuss this further in section 9.

CHAPTER 9: FLOW AND PLAYER EXPERIENCE

Astrojumper, Legerdemain, Sweet Harvest and Washboard all differ in the complexity of their rules and level of physical challenge presented, but were developed using the same approach to exergame design, wherein gameplay is built around a targeted form of exercise and gameflow theory. Previous chapters have presented data on players' physiological reactions to playing each of these games, along with brief descriptions of the feedback collected from players about their experiences. In order to gain more information on the psychological responses to play and analyze the extent to which we were able to promote flow, we administered the Flow State Scale-2, a 36-item measure of flow experience, to participants in the user studies of Sweet Harvest and Washboard, Legerdemain's second user study, and an additional small study of Astrojumper-Intervals. This section will present these data and discuss similarities and differences found among the four games.

9.1 Comparing Game Complexity and Physical Challenge

The two main dimensions of the exergame experience, according to Sinclair et al. (2007), are attractiveness and effectiveness, respectively, the psychological aspect of gameplay and the physiological aspect of exertion. Astrojumper, Legerdemain, Sweet Harvest and Washboard each offer a different type of game, in terms of game rules and goals, and require a different type and intensity of exertion. Figure 9.1 demonstrates where the gameplay complexity and physical challenge level of each game may be placed in relation to one another.

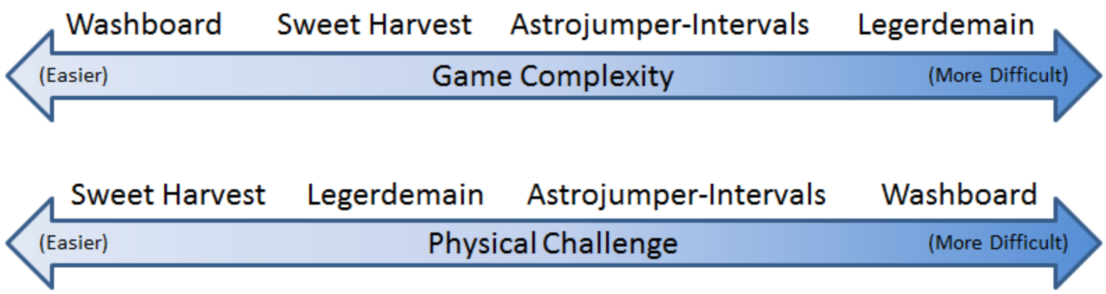


Figure 9.1: Comparing game complexity and physical challenge level of exergames.

Washboard has the simplest gameplay, and presents the most difficult physical challenge: the main goal is just to hit balloons that move across the screen, but the sit-up movements required to accomplish that goal, and to continue to do so throughout the game session, can become very strenuous. Sweet Harvest's goals are nearly as straightforward, as the instructions and fruits that appear on the screen guide players through each motion; however in contrast to Washboard, the physical demands of Sweet Harvest's gameplay are very low. The game goals presented by Astrojumper-Intervals are also relatively easy to understand (e.g. dodge objects) but their variety adds some complexity, and the aerobic movements required to play well over a 15-minute play session are moderately strenuous. Finally, the intensity of exertion necessary to do well in Legerdemain can nearly match that of Astrojumper-Intervals, especially with the use of weights as in the user study, but the larger number of game rules and the need to adapt to different opponent strategies results in Legerdemain being the most complex of the four games.

In this study, we wanted to investigate any impact the characteristics of game complexity and physical challenge level, or any particular game elements, had on player reactions and experiences. To do so we used two quantitative measures, the PANAS and FSS-2, and also looked at different trends in player feedback.

9.2 Player Experience Study

Table 9.1 summarizes several characteristics of the study participants.

Table 9.1: Summary of participant characteristics across user studies. Lifestyle Activity Rating: Self-rating of the amount of activity (not necessarily exercise) present in daily life, on a 7-point scale (1 = "Not active at all", 7 = "Extremely active"). Gaming Hrs Per Week: Self-rating of number of hours spent playing video games per week, on a 5-point scale where 2 = "1-3 hours per week" and 3 = "4-6 hours per week."

Game	Gender	Age (years)	Lifestyle Activity Rating	Gaming Hrs Per Week
Astrojumper-Intervals (N = 19)	Male (N = 12)	M = 22.36	M = 4.17	M = 2.05
	Female (N = 7)			
Legerdemain (N = 19)	Male (N = 14)	M = 22.57	M = 4.17	M = 2.26
	Female (N = 5)			
Sweet Harvest (N = 31)	Male (N = 27)	M = 23.9	M = 3.8	M = 2.71
	Female (N = 4)			
Washboard (N = 28)	Male (N = 21)	M = 23.62	M = 4.61	M = 2.27
	Female (N = 7)			
(Total) (N = 97)	Male (N = 74)	M = 23.11	M = 4.19	M = 2.32
	Female (N = 23)			

No significant differences in participants' average age, rating of lifestyle activity level, or hours per week spent gaming were found between the groups for each game condition.

Participants were recruited from UNC Charlotte students in the departments of computer science, kinesiology and psychology. All study sessions took place in the

Biodynamics Research Lab, with games displayed on a television screen similar to what participants might use as a display for traditional console gaming at home. Study sessions generally lasted between 30-50 minutes. After being informed of the study's procedures, participants were given a demographic survey and the PANAS questionnaire. Then they played one exergame: Washboard and Sweet Harvest involved approximately 5-8 minutes of gameplay, and Astrojumper-Intervals and Legerdemain took 15-20 minutes to play. Following the game session participants were given the FSS-2 to fill out, followed by the PANAS for the second time, and a final survey where they could provide any feedback.

9.3 Changes in Mood Resulting From Gameplay

Positive and negative affect are the two primary dimensions of a person's emotional experience. Positive affect (PA) refers to a state of being enthusiastic and alert; as described by Watson et al. (1988) high PA is, "a state of high energy, full concentration, and pleasurable engagement," while a person with low PA may in contrast feel sad or lethargic. Negative affect (NA) refers to feelings of distress or "unpleasurable engagement," and a person in a high NA state may feel anger, contempt or fear. A low NA state, however, may be one of calmness (Watson et al., 1988). Soundarapandian et al. (2010) showed a link between an exerciser's feelings after completing a workout routine and their likeliness to engage in the workout again, and Parfitt and Hughes (2009) discussed the importance of considering individuals' affective response to exercise when developing a physical activity program.

The Positive and Negative Affect Schedule (PANAS) was administered to participants before and after playing an exergame and allowed us to detect changes in mood possibly caused by the play experience. Table 9.2 summarizes the results from our pre-game and post-game administration of the PANAS during user studies.

Table 9.2: Changes in positive and negative affect resulting from gameplay; $p < 0.05$ indicates a statistically significant difference between pre- and post-PA or NA.

Game	PA Change (Post – Pre)	NA Change (Post – Pre)
Astrojumper-Intervals (N = 19)	M = 4.0, SD = 6.76; p = 0.019	M = -1.11, SD = 3.7; p = 0.21
Legerdemain (N = 19)	M = 2.78, SD = 5.35; p = 0.036	M = -1.32, SD = 1.42; p = 0.001
Sweet Harvest (N = 31)	M = 0.82, SD = 6.2; p = 0.47	M = -2.99, SD = 3.997; p = 0.000
Washboard (N = 27)	M = 2.09, SD = 4.56; p = 0.025	M = -3.22, SD = 3.19; p = 0.000
All Exergames (N = 96)	M = 2.19, SD = 5.77; p = 0.000	M = -2.35, SD = 3.42; p = 0.000

With the above definitions of PA and NA in mind, we might consider the most successful outcome to be the one in which PA is increased, and NA is decreased. For the overall group of exergame players, we can see this was the case (M = 2.19 point increase in PA, p = 0.000; M = 2.35 point decrease in NA, p = 0.000). While at least small PA increases and NA decreases are seen for each individual game, the Legerdemain and Washboard groups showed statistically significant results for both an increase in PA and decrease in NA, while Astrojumper-Intervals and Sweet Harvest did not. We will note, however, that the decrease in NA achieved by Legerdemain was not as great as that resulting from playing Sweet Harvest (p = 0.04) or Washboard (p = 0.009); likewise Astrojumper was not as effective at decreasing NA as Washboard (p = 0.044).

9.4 Flow State Scale-2 and the Nine Dimensions of Flow

The nine flow dimensions examined by the FSS-2 are challenge-skill balance, action-awareness merging, clear goals, unambiguous feedback, total concentration on the task at hand, sense of control, loss of self-consciousness, transformation of time, and autotelic experience. The following list contains summarized descriptions and example statements from the FSS-2 Manual (Jackson et al., 2010).

- Challenge-Skill Balance: Relates to a person's perception of challenge and skill, or their confidence regarding what they may do in a situation.
    - "I was challenged, but I believed my skills would allow me to meet the challenge."
- Action-Awareness Merging: Relates to absorption or a feeling of oneness with an activity, associated with a sense of effortlessness or spontaneity.
    - "I made the correct movements without thinking about trying to do so."
- Clear Goals: A feeling of knowing exactly what to do; provides focus to actions.
    - "I knew clearly what I wanted to do."
- Unambiguous Feedback: Relates to the ease of receiving and interpreting feedback on actions.
    - "It was really clear to me how my performance was going."
- Total Concentration on the Task at Hand: All focus is on the task being performed; epitomizes the flow state.
    - "My attention was focused entirely on what I was doing."
- Sense of Control: Relates to feeling in control, and the possibility of maintaining control when challenged (relates to challenge-skill balance).
    - "I had a sense of control over what I was doing."

- Loss of Self-Consciousness: Occurs when an individual is no longer concerned with what others think of them, and also is free from self-criticism.
    - “I was not concerned with what others may have been thinking of me.”
- Transformation of Time: A result of intense involvement in an activity, time may seem to pass more slowly or more quickly than expected. Perhaps the least frequently experienced flow dimension.
    - “The way time passed seemed to be different from normal.”
- Autotelic Experience: The extent to which an experience is intrinsically rewarding; described by Csikszentmihalyi as the end result of the other eight flow dimensions.
    - “I really enjoyed the experience.”

The Flow State Scale-2 (FSS-2) was given to participants after playing an exergame. This questionnaire presents a series of statements related to the nine dimensions of flow, such as the examples given above, and respondents indicate their agreement with each statement on a 5-point scale (1 = “Strongly Disagree” and 5 = “Strongly Agree”). Flow dimension score results were calculated according to instructions in the FSS-2 manual, and are presented in Table 9.3. The lowest possible score for a flow dimension is 1 (the participant did not experience the aspect of flow), and the highest possible score is 5 (the participant did experience the aspect of flow). A score of 3 may indicate some degree of agreement or, alternatively, ambiguity of relevance to the person’s flow experience; we will generally regard it as not strongly showing that a dimension of flow was or was not felt as part of the experience (Jackson et al., 2010).

Figure 9.2 shows that generally, our exergames had the highest scores for the flow dimensions of clear goals, concentration (“total concentration on the task at hand), and autotelic experience; and the lowest scores for action-awareness merging and time transformation. On average, Legerdemain was scored more highly than the other games in six of the nine flow dimensions (challenge-skill balance, action-awareness merging, feedback, concentration, time transformation and autotelic experience) and Washboard was scored more highly than the other games in the remaining three flow dimensions (clear goals, sense of control, and loss of self-consciousness).

Table 9.3: Mean item scores for each of the nine flow dimensions for all exergames.

(Mean)	Legerdemain	Washboard	Sweet Harvest	Astrojumper -Intervals	All Exergames
Concentration	4.276	4.139	4.161	4.092	4.164
Clear Goals	4.118	4.213	4.145	4.092	4.148
Sense of Control	3.987	4.111	4.048	3.908	4.026
Loss of Self-Consciousness	4.026	4.093	3.96	3.776	3.974
Unambiguous Feedback	4.145	4.139	3.782	3.763	3.95
Autotelic Experience	4.132	3.926	3.798	3.974	3.935
Challenge-Skill Balance	4.053	3.935	3.839	3.697	3.88
Action-Awareness Merging	3.618	3.583	3.532	3.579	3.573
Transformation of Time	3.526	3.343	3.355	3.395	3.393
Flow Score (Sum of Item Scores)	35.882	35.482	34.621	34.276	35.044

Table 9.4: Standard deviations of item scores for each of the nine flow dimensions for all exergames.

(SD)	Legerdemain	Washboard	Sweet Harvest	Astrojumper -Intervals	All Exergames
Concentration	0.577	0.582	0.792	0.718	0.675
Clear Goals	0.516	0.484	0.562	0.528	0.519
Sense of Control	0.69	0.625	0.53	0.608	0.601

Loss of Self-Consciousness	0.849	0.809	0.839	0.82	0.824
Unambiguous Feedback	0.608	0.641	0.771	0.733	0.711
Autotelic Experience	0.679	0.635	0.881	0.558	0.718
Challenge-Skill Balance	0.504	0.685	0.546	0.715	0.618
Action-Awareness Merging	0.747	0.838	0.793	0.759	0.779
Time Transformation	0.916	0.815	0.901	0.822	0.854
Flow Score	4.184	4.045	4.056	3.615	3.98

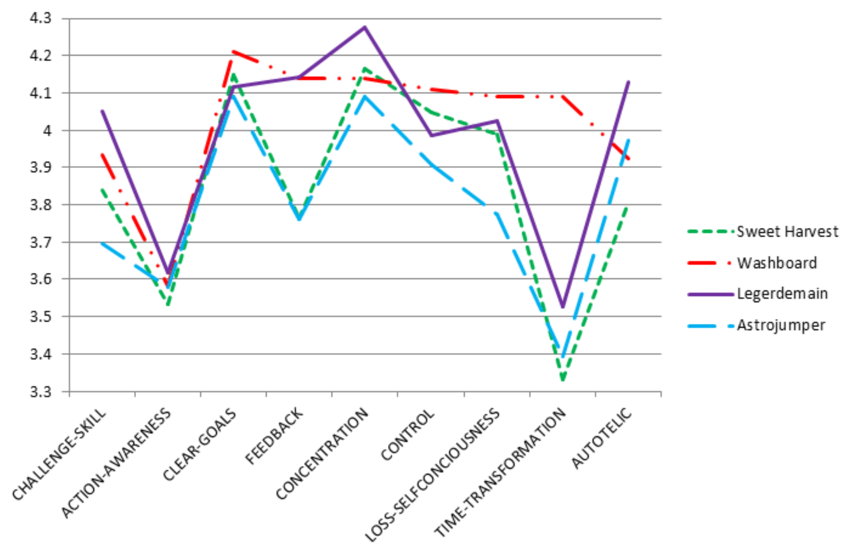


Figure 9.2: Mean flow dimension scores as presented in Table 9.3.

We compared mean flow scores for the exergames, both individual and overall, with published descriptive mean scores for non-competitive exercise and sports (Jackson et al., 2010). For the combined (all games) participant group, mean flow scores for challenge-skill balance were higher than those for both exercise (exercise M = 3.74; $p = 0.029$) and sports (sports M = 3.69; $p = 0.003$); scores for the clear goals dimension were higher than those for exercise (exercise M = 3.98; $p = 0.002$); scores for the concentration dimension were higher than those for both exercise (exercise M = 3.69; p = 0.000) and sports (sports M = 3.7; p = 0.000); and scores for the sense of control dimension were also higher than those for both exercise (exercise M = 3.8; p = 0.000) and sports (sports M = 3.7; p = 0.000). Mean scores for the autotelic experience dimension were higher for exercise than for exergaming (exercise M = 4.18; p = 0.001), it is possible that traditional exercise would have clearer presumed benefits and result in more personal satisfaction for a participant, in contrast to the act of engaging in a game-based workout for the first time. Individually, Legerdemain scored better in challenge-skill balance than exercise (p = 0.015) and sports (p = 0.006); Washboard scored better in clear goals than exercise (p = 0.019) and better in feedback than sports (p = 0.032). All games individually scored better in concentration than exercise (Astrojumper p = 0.025, Legerdemain p = 0.000, Washboard p = 0.000, Sweet Harvest p = 0.002) and sports (Astrojumper p = 0.029, Legerdemain p = 0.000, Washboard p = 0.001, Sweet Harvest p = 0.003). Sweet Harvest and Washboard scored better in sense of control than exercise (Washboard p = 0.016, Sweet Harvest p = 0.014) and sports (Washboard p = 0.002, Sweet Harvest p = 0.001). Finally, Sweet Harvest scored lower than exercise in the autotelic experience dimension (p = 0.022) as did Washboard (p = 0.048). All other comparisons yielded no statistically significant differences.

We also predicted some relationship between changes in mood and flow scores, believing that a better flow experience might result in an improved mood after playing. No correlations between the change in negative affect and individual flow item scores were seen, but changes in positive affect were statistically significantly correlated with all flow dimensions except for clear goals and feedback (for all exergames, N = 96), as follows: challenge-skill balance ($r = 0.43$, $p = 0.000$); action-awareness merging ($r = 0.322$, $p = 0.001$); concentration ($r = 0.31$, $p = 0.002$); sense of control ($r = 0.319$, $p = 0.002$); loss of self-consciousness ($r = 0.284$, $p = 0.005$); time transformation ($r = 0.266$, $p = 0.009$); and autotelic experience ($r = 0.457$, $p = 0.000$).

9.5 Trends in Player Feedback

At the conclusion of a study session, participants were asked for feedback about what they either liked or disliked about the game they had just played. Comments for all games commonly mentioned the opinion that they were fun, creative ways to exercise and in most cases felt like an effective workout; the most commonly stated negative aspect was the Kinect's tendency to occasionally lose track of the player's position, making control of the game difficult. In order to identify broad patterns among feedback received, the participants who mentioned a game aspect that they liked were counted, as were the participants who mentioned a game aspect that they disliked (those including both positives and negatives in their comment are counted twice), with numbers compared to the total number of respondents. The majority of those who played Washboard, Legerdemain or Astrojumper gave positive feedback. For Washboard, 23 of 27 (85%) gave positive comments and 9 of 27 (33%) gave negative comments; for Legerdemain, 16 of 20 (80%) were positive and 4 of 20 (20%) negative; and for Astrojumper, 15 of 20 (75%) were positive and 7 of 20 (35%) negative. Sweet Harvest's results showed a different trend: 16 of 30 respondents (53%) mentioned aspects of the game or play experience that they liked, but 18 of 30 (60%) commented on what they disliked about the game. The following list contains descriptive examples of participants' comments for each of the four games.

- Washboard
    - "I like the game play. It made time go by quicker then I thought it was and I didn't realize how much I was actually exercising until after when my abs were burning."
    - "I liked how it worked my abs and how challenging it was to get my position just right to get all of the balloons. I didn't like how the speed slowed down and sped up. It messed with me and when it slowed down, I had to hold my position longer!"
    - "I liked it. I would love to have more time to play it so I could practice and be more aware of how my body was moving. This would be a great way to entice me to do sit ups if I had more time to spend with it."
- Legerdemain
    - "I really liked the game because I lost track of time and got a good workout in while still having fun. I think the level of difficulty is good and the user interface is very easy to follow and understand. Thanks!"
    - "Some of the enemies (the clear slimes?) were not affected by the wall spell and I was unsure why. Sometimes it felt like the enemies were moving too fast towards me to perform an adequate spell in time. Overall, I enjoyed the game despite my issues with the kinect."
    - "I enjoyed how complex it seemed at times. It really kept me pushing myself as the levels got higher."
- Astrojumper

  - "I liked that it was challenging but not to the point where it was too difficult to keep up with."
  - "i liked the exercise part of the experience but the game itself got boring after awhile."
  - "The game itself is a simple concept but it was very fun and I feel like I've gotten my workout done for the day"
- Sweet Harvest
  - "Was not too hard, but still challenging and fun to do. More activities could be added to avoid repetitive exercises. I wasn't exactly sure what I was supposed to do in the ant section."
  - "Accuracy in stretching motions, cute/fun appearance. Did not like responsiveness of Kinect. One part was impossible because my wingspan was not wide enough and that's why I was not NUMBER ONE. :)"

9.6 Discussion

Previous work that has discussed the importance of designing games to support flow, or the relationships between flow, emotion (affect) and enjoyment seems to be supported by our results from this study. We did find correlations between the change in positive affect and most flow dimensions, as stated above, and while correlations between PA and the flow scores for clear goals and feedback were not found to be statistically significant here, the importance of including these in game design is still very clear, from past research and, for example, from demonstrated differences in user responses from the two Legerdemain studies.

From the results presented above, we might consider Washboard and Legerdemain to be the more successful of the four exergames. PANAS results from these two game groups show both increased PA and decreased NA following game sessions, and these games have the highest average scores for each flow dimension from the FSS-2 questionnaire. Also, Washboard and Legerdemain player comments showed the greatest differences between numbers of participants who commented positively as opposed to negatively about the game. This pattern is interesting as these are the two games that offer the highest level of challenge, but in different areas: the physical challenge of completing Washboard's sit-ups workout is arguably the most difficult among all four games, but Legerdemain's gameplay complexity perhaps offers the highest cognitive challenge, especially for first-time players. Astrojumper-Intervals was also able to noticeably increase players' positive affect, and although it had the lowest average scores for six of nine flow dimensions, showed a similar majority of positive over negative comments from players. The greatest overall difference in participant response was seen for Sweet Harvest, with no significant change in PA and a slight majority of negative comments over positive from players.

We have seen from the first Legerdemain study that players' backgrounds or habits can influence the first experience they have with a new exergame. Our other studies have also shown the impact players' expectations regarding types of games or exercise, or their perceptions of exergames' intended users, can have. However, our exergames are primarily different in the levels and types of challenges that they present to players, and this observation has been the most useful in explaining why players' reactions to the games were also different.

If designing for a general audience, challenge-skill balance seems to be supported as one of the most important aspects of a game. Balancing between game challenge and player skill, or continuously providing opportunities for players to practice their abilities and then increasing the challenge level, and so on, is an intuitive concept that is useful when planning a game's structure and pacing. It is an integral part of the flow experience, and when supported by other good game design elements like giving players clear goals and feedback, can lead to the other aspects of flow and an intrinsically rewarding experience. Design or implementation details, though, are not necessarily straightforward: exergame designers need to consider the different forms of challenge that may be offered, the different skills needed to answer them, their alignment with the game project's goals, and their potential impact on the game's short- and long-term success. While by definition exergames contain aspects of both video games and exercise, in practice the types of challenges included in gameplay may focus more on one than the other. Challenges may be mostly physical, coming from the exercises performed while playing; or mostly cognitive, coming from the set of game rules and objectives that must be learned to play well. The type of challenge will define the type of skill required to address it, and will impact the purpose best supported by the game (e.g. exercise or entertainment) as well as, possibly, the type of player most attracted by it. Finally, the game's ability to meet the player's expectations for exercise effectiveness or game attractiveness and support their goals will affect its short- and long-term appeal.

Washboard, for example, implements very simple game rules and then focuses strongly on one particular physical challenge: sit-ups. These are presented in slightly different ways in the course of a game session and the game's difficulty does change over time, as the difficulty adjustment system reacts to player performance and as the player becomes fatigued, but the main action the player is performing and the stimuli they are asked to pay attention to (balloons on the screen) remain the same throughout. In its current form Washboard is well able to meet player expectations for workout effectiveness and so may appeal to those wanting to develop their physical skills. It is also appealing as a novel activity to a wider group, as we have seen from the study. However its long-term ability to attract those who are not particularly motivated to exercise may be limited. Players who did mention wanting more time with the game cited its efficacy as a workout tool instead of a source of entertainment, as in this example: "I liked it. I would love to have more time to play it so I could practice and be more aware of how my body was moving. This would be a great way to entice me to do sit ups if I had more time to spend with it."

Alternatively, designers can work to include challenges of both types, creating a game that requires players to use both physical and cognitive skills. These may be implemented separately or in combination: the game could switch between activities that require different skill types, or aim for an activity that requires players to think or strategize about their movement choices and then translate their choices into physical actions. Similarly, challenge also arises from variety in gameplay, as the player is presented with and must learn to adapt both physically and cognitively to new stimuli. This approach has several benefits. In addition to being better able to support both exertion and entertainment in one game, it potentially will result in a game that will appeal to an audience with a wider variety of motivating goals or interests. Also though, within the game itself, the application of one type of skill (physical or cognitive) in response to a challenge can distract the player from the demands of using the other type of skill. Specifically, we can use the cognitive challenges of making strategic choices and interpreting feedback during gameplay to distract players from the difficulty or possible discomfort of physical exertion.

For Legerdemain, because of its higher level of game complexity, it was generally more challenging for new players to learn the rules of the game and choose a strategy that let them defeat an opponent than it was for them to adjust to the initial physical demands of gameplay. The cognitive challenges here were able to hold players' attention through the game session, despite the exertion. Several player comments mentioned this explicitly, as shown by these examples: "I really enjoy the game. I felt like I was getting a good workout while being distracted by the activities in the game. If my everyday workout consisted of this game I think I would exercise a lot more," or, "The time went by in a fast matter and [I] forgot that I was exercising while playing a video game." Other comments, such as those included in section 9.5 mentioned having both a good workout and a fun experience, indicative of the attractiveness-effectiveness balance achieved.

Astrojumper is not as physically difficult as Washboard, and is not as complex a game as Legerdemain, but still presents challenges of both types. The cognitive challenge of learning the game's rules is not as high initially, but the periodic introduction of new mini-games and game mechanics increases the challenge level to an extent by requiring the player to adapt both mentally and physically, both to the new gameplay and to repeatedly switching between activities. Astrojumper also provides what is possibly our best example of a game mechanic that combines cognitive and physical challenge, in that as players attempt to dodge the planets flying toward them, they must constantly make quick decisions about where or how to move to avoid the obstacles which can require considerable attention. We can contrast Astrojumper, Legerdemain and Washboard with Sweet Harvest, which has simple gameplay and requires only low levels of exertion. Players are able to learn the rules quickly and so do not necessarily need to focus all of their attention on the game, and are also not overly challenged by the game's physical aspects, leading to a less enthusiastic response overall.

Future research into single-player exergame experiences could further investigate several aspects of the work presented here. The question of motivating repeat play, for example, is important as one of the primary supporters of exercise effectiveness. Data from the PANAS along with player feedback has indicated our games' potential for success beyond a single session, and following studies could perform a more in-depth examination of why and how well games such as ours are actually able to sustain player interest. Likewise, adding multiplayer or other social elements would also be likely to affect sustained motivation, but also might change the way that flow experiences in exergames need to be considered. This study of player experiences with our four novel exergames suggests multiple, additional avenues of investigation into game elements that increase and balance exergame attractiveness and effectiveness, but has also allowed us some insight into important dimensions of gameflow, how they affect player experiences, and how they may be addressed in exergame design.

CHAPTER 10: A DESIGN APPROACH FOR EXERGAMES

We have investigated the practical application of an exergame design approach based on Sinclair et al.'s (2007) dual-flow model of attractiveness and effectiveness through the development and evaluation of a collection of custom exercise games. Our approach, first used successfully with the original Astrojumper, was then applied to games intended to support different types of exercise with new mechanics: Astrojumper-Intervals, Legerdemain, Sweet Harvest and Washboard. Overall, we found we could fairly consistently produce exergames that players had fun with, and that could meet goals for exercise type and intensity. Also, though, we were able to compare the elements of our games that did not work with those that did, leading to further insights regarding attractive and effective exergame design.

10.1 Exergame Effectiveness

In the dual-flow model, a balance between an exergame's intensity and a player's fitness level leads to flow, while an imbalance results in either no benefit to the player's fitness level, the player's failure to complete the game if the intensity level is too high, or fitness deterioration if the intensity level is too low. In order to address the issue of exergame intensity, Sinclair et al. discuss proper workout structure, with warm-up and cool-down periods before and after a workout, and the importance of considering a workout's recommended duration and frequency; they also cite heart rate as a useful measure of the balance between intensity and fitness (Sinclair et al., 2007). We included exercise guidelines published by the ACSM and CDC, and the related FITT principle (frequency, intensity, time and type) as part of our design process. For each game, the desired type, intensity and duration of the workout was decided first, with gameplay and mechanics then designed to support the exercise goals.

- Astrojumper and Astrojumper-Intervals support a 15-minute moderate-intensity aerobic workout, and implement a dynamic difficulty adjustment system that modifies game difficulty based on workout phase (warm-up, workout or cool-down) and player performance. Further, Astrojumper-Intervals demonstrates how the concept of interval training may be applied to game progression to increase exercise effectiveness.
- Legerdemain supports a combination of light-to-moderate aerobic activity and strength training in a 15-20 minute play session. The mix of exercise types increases the efficiency of the workout time. Legerdemain also implements a difficulty adjustment system that is more flexible, and applicable to more game types, than that of Astrojumper.
- The Sweet Harvest and Washboard prototypes demonstrate mechanics and difficulty adjustment systems for short workouts involving different exercise types: low-intensity dynamic warm-up and stretching activities, and high-intensity core strength training respectively.

10.2 Exergame Attractiveness

The attractiveness dimension of the dual-flow model is based on the gameflow concepts from Sweetser & Wyeth (2005), itself based on Csikszentmihalyi's original flow construct. A balance between gameplay challenge and player skill here will also promote a flow experience, while an imbalance results in anxiety or boredom if the player's skill level is too low or too high in relation to game challenge, or apathy if both challenge and skill levels are low (Sinclair et al., 2007). Sweetser & Wyeth's gameflow components include concentration, challenge, player skills, control, clear goals, feedback, immersion and social interaction; our work has afforded insights into several of these as we have applied them to exergame design.

Challenge and Skill: As discussed in section 9 on the player experience study, our results support challenge-skill balance as the most important component of a flow experience (Sinclair et al., 2007 citing Jackson & Csikszentmihalyi, 1999). For an exergame, challenge comes from both the physical exertion of the motion mechanics and the cognitive effort of learning and practicing game rules and abilities; these challenges need not be equally present for an exergame to meet its initial goals for attractiveness and effectiveness, but the game's capability to sustain both types of challenge across multiple play sessions may affect its long-term usability. Also in support of balancing challenge and skill, it is useful to consider how physical and cognitive skills are developed. For traditional games it might be assumed that player skill increases along with time spent playing, and likewise, more exertion over a period of time results in improvements to fitness. However in a single exergame session, a player will be able to improve their knowledge of how to play the game but become physically tired, impacting their performance. Any difficulty adjustment system put in place, then, can potentially adjust both types of challenge but should be flexible enough to respond appropriately, and continuously, to changes in a player's level of performance.

Clear Goals and Feedback: Information presented by the game to the player is key in teaching skills, allowing players to learn both what they should be doing, and how well they are doing it. The physical demands of an exergame are easily able to take a player's attention away from HUD elements, so an exergame needs to be even more selective about the information it presents on-screen than a traditional game. We found that short instructional phrases, using large text and presented centrally and briefly, worked well, but that audible instructions and feedback were some of the most effective in terms of allowing players to receive and process the information while not being required to remove much attention from the exertive gameplay.

Concentration: Sweetser & Wyeth (2005) state that to keep a player's concentration fully on a game, the game should, "provide a lot of stimuli from different sources" while still being appropriate for a player's cognitive limits. However a player utilizing both cognitive and physical skills at once may have further limitations that will need to be considered when designing game challenges. For example, in one of our early exergame prototypes players were asked to catch falling colored circles with their hands, and then reach up or side-to-side to place the circles in containers with matching colors. Circles that fell too far could be kicked back up with the player's feet. While this seems like a very simple cognitive challenge, we saw in playtesting that it became too complicated when the physical gameplay was attempted at the same time, demonstrating the importance of both designing and testing while considering the combination of demands on the player's attention.

Sinclair et al. offer good discussion of exergame attractiveness and effectiveness separately, but we have also found that some of the most successful elements of our exergames fall into the intersection of the attractiveness and effectiveness dimensions. The difficulty adjustment systems discussed previously are part of this, as they can adjust both cognitive and physical challenges in an attempt to balance both with the player's skills. Additionally, we have been able to approach physical movement itself as a game, and an opportunity for player creativity and expression.

10.3 Exergame Support for Creative Physicality

Reflective of the thoughts on designing for motion put forth in Hummels et al. (2007), we have come to believe that the potential richness of the physical interaction space can be leveraged to greatly improve exergame experiences, more so than has been accomplished by most current commercial or academic exergames. In many traditional video games, the challenges or obstacles presented allow players to exercise some level of creative problem solving to overcome them. We have found that creative problem solving can be applied to physical as well as cognitive challenges, and in our exergames have experimented with ways to allow players some creative leeway in the movement choices they are able to make, while still encouraging movements or sequences of movements that provide effective exercise even if the movements are not those of traditional exercise routines (e.g. yoga, series of squats or lunges, etc.). It is easier to understand that those established, traditional exercises are effective; however, we have an opportunity through exertion game design to allow players to exercise choice in how they move, and take advantage of games' capability to encourage creative play. It is also worth noting that some freedom of movement is one way to not only cater to individual play styles and preferences, but also to reduce some risk of injury as players would not be required to perform repetitive, possibly uncomfortable actions in order to succeed in the game. Creative physicality as a combination of attractiveness and effectiveness exergame elements has a very positive effect on players' experiences with an exergame, as seen for example in the responses both children and adults had to playing Astrojumper.

10.4 Conclusion

Exergames have great potential to reach wide audiences and promote increased activity in daily life, and continued research in the field will further improve our ability to design for fun, effective motion gaming. Our research has demonstrated how exercise guidelines and flow principles may be applied toward the creation of engaging exertion games, and has contributed toward our understanding of what aspects of exergames are most influential and most successful from a player experience perspective. Future research will be able to expand upon the work we have presented here, investigating systems or devices able to support many types of movements and make exergames better able to fulfill the requirements of a balanced workout program, and furthering our knowledge of how to design for flow experiences in support of motivating effort and playability.

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APPENDIX A: MEASURES

A.1 Borg Rating of Perceived Exertion (RPE) Scale

(Borg, 1998)

Choose the number from below that best describes your level of exertion:

6 (No exertion)

7

(7.5 – Extremely light)

8

9 (Very light)

10

11 (Light)

12

13 (Somewhat hard)

14

15 (Hard)

16

17 (Very hard)

18

19 (Extremely hard)

20 (Maximum exertion)

A.2 Positive and Negative Affect Schedule (PANAS)

(Watson et al., 1988)

The following scale consists of a number of words that describe different feelings and emotions.
Read each item and then mark the appropriate answer next to that word. Indicate to what extent you feel this way right now.

	1 (Very slightly or not at all)	2 (A little)	3 (Moderately)	4 (Quite a bit)	5 (Extremely)
interested					
distressed					
excited					
upset					
strong					
guilty					
scared					
hostile					
enthusiastic					
proud					
irritable					
alert					
ashamed					
inspired					
nervous					
determined					
attentive					
jittery					
active					
afraid					

A.3 Flow State Scale-2

(Jackson et al., 1992; 2010)

The Flow Scales
Instrument and Scoring Guide

Susan A. Jackson, Robert C. Eklund, & Andrew. J. Martin

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