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Supporting an Interval Training Program with the Astrojumper Video Game

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Abstract

We have previously developed Astrojumper, an exercise video game with a space theme that uses the Microsoft Kinect to support full-body exertion play. In this paper, we present the design and evaluation of Astrojumper-Intervals, a new version of our Astrojumper exergame, that explores methods of improving upon the previous game in both aspects of enjoyment and exercise effectiveness. We also investigate how interval training, an established exercise technique used to increase the efficiency of time spent exercising, may be incorporated within a video game. A user study of 34 adult participants compared Astrojumper-Intervals with the original Astrojumper game in terms of exercise effectiveness, measured using heart rate, energy expenditure, and ratings of perceived exertion; and game enjoyment, measured with Likert scale ratings and qualitative feedback. We found that Astrojumper-Intervals elicited statistically significantly greater energy expenditure and heart rate increases than the original game. Also, despite participants' wide variety of exercise motivations and opinions of games as exercise tools, the overall response to our game was very positive, with 27 of 34 participants preferring the new Astrojumper-Intervals game.

Keywords: exercise video games, exergame evaluation, interval training

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Exercise video games, alternatively “exergames” or “active video games,” are designed to elicit energy expenditure in players, using gaming technology and mechanics that support various forms of physical activity. Current, commercially available motion-sensing devices and gaming platforms, including the Nintendo Wii and Wii Fit balance board, dance pads, Sony’s PlayStation Move and the Microsoft Kinect, have increasingly provided developers with the tools to create games controlled by players’ physical movements. According to the Entertainment Software Association’s 2012 data, the average household owns at least one dedicated game console, PC or smartphone, and game players include people of all age, gender and ethnic groups (ESA, 2012). Exergames can promote increased physical activity among this wide audience through engaging and motivating play, which is especially important today given that the prevalence of obesity among adolescents and adults in the U.S. is a recognized problem. However, although exercise video games have great potential to address this problem, currently existing or available games still struggle to balance enjoyable gameplay with effective exercise, as Sinclair, Hingston and Masek described in their dual-flow model of attractiveness and effectiveness: respectively, the psychological aspect of gameplay and the physiological aspect of physical activity (Sinclair, 2007). We believe this issue can be addressed through the finding of new ways to combine knowledge from health and exercise-related research fields with the domain of video game design.

Background

Exercise video games have recognized potential to use engaging play to motivate increased physical activity. For those without access to a gym or safe, practical outdoor environments, exergames afford the opportunity to exercise within the home (Ahn, 2009). Awareness of physical activity levels, which is an important element in behavioral change adoption, can be greatly increased through exergame play (McLean, 2003); and exergames are also able to provide feedback on players' performance and progress and help to develop individualized short- and long-term fitness goals. Exergames have also been effectively used for rehabilitation (Betker, 2007; Kizony, 2003). However, the previously mentioned balance between game attractiveness and exercise effectiveness discussed by Sinclair et al. (2007) remains a significant challenge (Berkovsky, 2010; Hämäläinen, 2005). A number of recent studies concerning the exercise effectiveness of active video games agree that these games are able to elicit light to moderate intensity energy expenditure, equivalent to activities such as walking or jogging. This is a level of energy expenditure sufficient to contribute to the recommended amounts of daily physical activity described by the American Heart Association and American College of Sports Medicine guidelines. These studies were conducted across age groups: children (Maddison, 2011; 2007; Bailey, 2011; Graf, 2009; Lanningham-Foster, 2009), adolescents (Graves, 2010; 2008), and adults (Miyachi, 2010; Lanningham-Foster, 2009). Additional positive effects of exergaming have also been noted. One study showed that a six-month period of active exergame use resulted in a small but definite positive effect on body composition in overweight and obese children (Maddison, 2011). Other studies have shown higher adherence to exercise programs that use active video gaming, when compared to programs using more traditional forms of exercise (Rhodes, 2009; Mellecker 2008). However, there are studies that do not have similarly positive results. White, Schofield and Kilding (2011) examined energy expenditure in boys age 11.4 +/- 0.8 years engaged 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). They found no significant difference in energy expenditure between active gaming and walking, and concluded that the activity in these games was not intense enough to contribute to the current daily activity recommendation for children (White, 2011). A different study of adolescents, young adults and adults playing Wii Fit activities found that although moderate intensity activity was elicited by the games for all age groups, heart rates were not raised to the point necessary for maintaining cardiorespiratory fitness (Graves, 2010).

Astrojumper

We have previously designed and evaluated Astrojumper, an exercise game developed for a Cave Automatic Virtual Environment (CAVE) virtual reality system, that used electromagnetic trackers to detect player movements. Astrojumper was successful in both attractiveness and effectiveness aspects, as measured by qualitative player feedback and a significant increase in heart rate over a 15-minute play session (Finkelstein, 2011). We have also previously developed a version of the Astrojumper game that utilizes the Microsoft Kinect for player tracking. The Kinect technology is more accessible than the CAVE system, and we also take advantage of the Kinect's more accurate and higher-resolution body tracking abilities. We have now developed a second version of the Astrojumper game: Astrojumper-Intervals, introduced in Nickel (2012). Astrojumper-Intervals was designed to improve upon the original game in two areas. First, the variety of game mechanics and physical movements used during play was increased, in order to improve player enjoyment and the game's ability to motivate repeat play, with the aim of encouraging exercise that results in health benefits. 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 investigate how game elements could be combined with established exercise training practice; to this end we based the gameplay progression on an interval training framework. This paper presents details of the design of Astrojumper-Intervals and the study conducted to compare it with the Kinect version of the original Astrojumper game.

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 (Karp, 2011; Boutcher, 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.

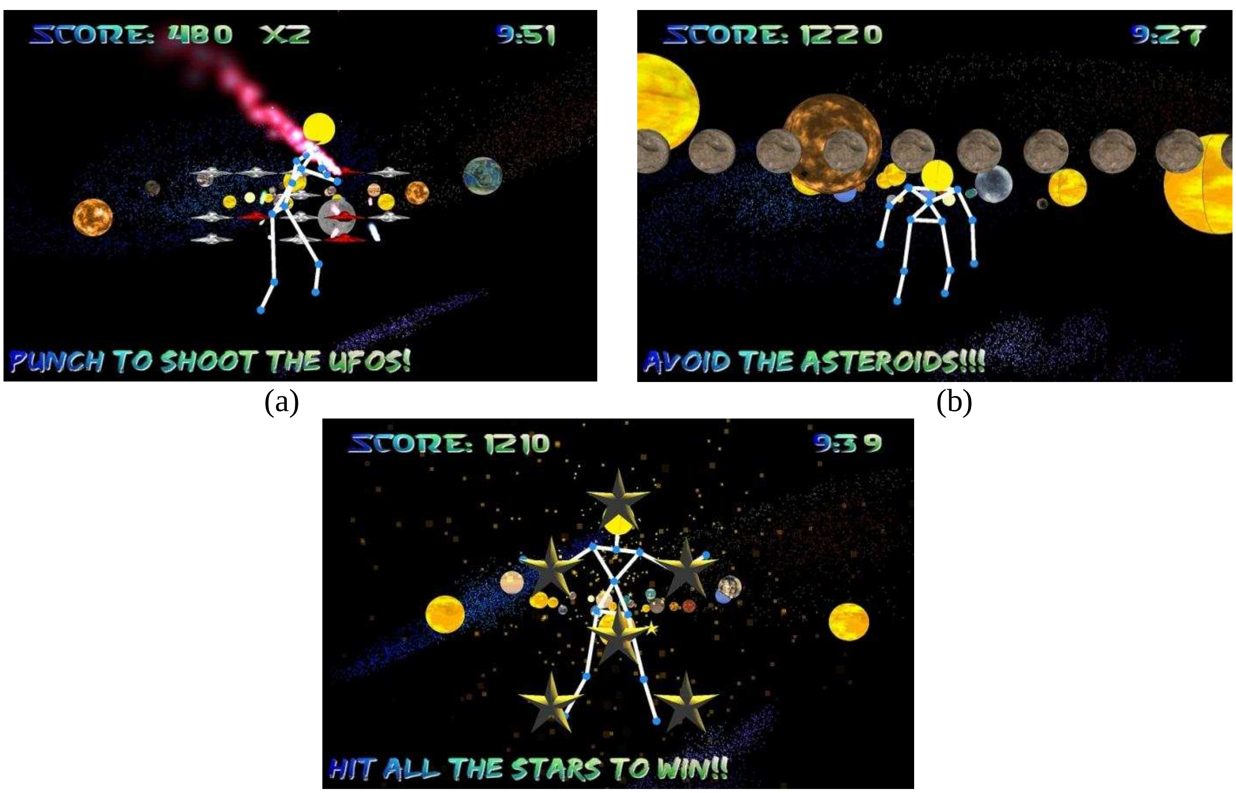
Astrojumper-Intervals

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).

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 lasers) 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 shoulder, elbow and hand, and right and left hip, knee, and foot. The game is structured to include a beginning warm-up period, a main exercise period, and a final cool-down period in accordance with the ACSM's guidelines for workout phases (American College of Sports Medicine, 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, where the speed of gameplay may be increased or decreased based on the player’s success rate, but the difficulty of the mini-games is restricted from falling below a defined level. This is done in order to allow the mini-games to maintain a higher-intensity activity requirement. The gameplay of these three mini-games is described in the following sections.



(a) (b) (c)

Figure 1: Screenshots of the Astrojumper-Intervals mini-games. (a) Space Invaders, (b) Asteroid Belt, and (c) Space Rock Band.

Space Invaders

In the Space Invaders mini-game, 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, finally destroying 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. (See Figure 1-a.)

Asteroid Belt

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 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. (See Figure 1-b.)

Space Rock Band

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 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. Points can be earned by successfully hitting stars, and additional points are given for hitting all possible stars. (See Figure 1-c.)

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 minigame 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 are followed by one minute of dodging planets, for the lower-intensity exertion period.

Evaluation

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. Table 1 includes descriptive data on the 34 participants: the range, average, and standard deviation for age, height, weight, and Body Mass Index.

Table 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 $\left(\frac{Weight}{Height^2}\right) * 703$, with results in the following categories: 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 falls 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. 16 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 = low frequency, 1-3 hrs/week; 2 = 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").

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 FIT armband to place around their upper left arm, which would measure energy expenditure

(METs) 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. An initial resting heart rate measurement was taken using a Sportline Solo 925 heart rate monitor, and 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 game play. 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 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.

Evaluation of Exercise Effectiveness

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 FIT armband was used to collect average METs (metabolic equivalent of task) data during each play session; this is a measure of energy expenditure during physical activities. 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).

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 statistically 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 are 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 causing a statistically significantly ($p = 0.018$) greater increase in heart rate: Astrojumper-Original pre-game HR ($M = 90.42$) and post-game HR ($M = 113.55$) compared with Astrojumper-Intervals pre-game HR ($M = 87.29$) and post-game HR ($M = 119.15$).

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, clearer results could potentially be obtained using an increased participant sample size, or with a sample population of less normally active participants.

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. In evaluating the effectiveness of a game's exercise, it would be beneficial to form a clearer picture of peak HR reached, and the length of time an increased heart rate is maintained. Also, no correlation 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.

Evaluation of Game Attractiveness

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.

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 either 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.

Discussion

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 is allowed to engage in while playing.

Despite the positive response to Astrojumper, participants' opinions on whether or not video games in general can be effective and motivational exercise tools reflect awareness that the state of currently available exergames, or at least their perception, 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."

As exergame research advances, developers will become more experienced with the design requirements for enjoyable physical activity as well as enjoyable gameplay, and with more sophisticated uses of commodity motion-sensing technology. We will be better able to integrate the fields of game design and exercise science, to create active video games that appeal to audiences of all ages, interests, and goals. The Astrojumper interval training game offers one example of how this may be done, and future work will aim to make further improvements to the incorporation of exercise techniques with established game design practice, as well as to the methods used to evaluate exergames' potential to help players reach long-term fitness goals.

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