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Physiological Responses to Active Video Games Compared to Treadmill Walking and TV Watching in Obese Children and Adolescents

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ABSTRACT

***International Journal of Exercise Science* 14(7): 519-532, 2021.** The purpose of this study was to examine the physiological responses to playing different active video games (AVG), as well as document the activity level exerted during AVG in relation to treadmill walking (TM) and watching television (TV). 20 youth (age 11-17 yr) with obesity were recruited from the Healthy Lifestyle Clinic and underwent testing under six randomized conditions: 1) TM, 2) TV, 3) Fitnexx, 4) river rush (RRH), 5) reflex ridge (RFR), and 6) space pop (SP). RRH, RFR, and SP are active video games for the Xbox 360. Fitnexx is a prototype AVG. Each test lasted approximately ten minutes each with ten minutes between conditions and participants wore a wireless physiological monitor (Zephyr BioHarness™3) for all tests. Physical activity was assessed via accelerometer, along with heart rate (HR). Rating of Perceived Exertion (RPE) was also gathered for each condition. Repeated-measures ANOVA examined condition differences. Subjects were age 13.3 ± 2.1 years old with BMI 38.7 ± 7.9 ($kg \cdot m \cdot s^{-2}$). Fitnexx had the highest activity level (0.63 ± 0.19g ~ jog), while activity levels for TM (0.20 ± 0.04g), RRH (0.29 ± 0.05g), RFR (0.31 ± 0.07g), and SP (0.21 ± 0.05g) were moderate (~walk), $Ps < 0.05$. Fitnexx had the highest HR (157 ± 13 bpm; $Ps < 0.001$), compared to TM (117 ± 18 bpm), RRH (128 ± 19 bpm), RFR (127 ± 18 bpm), and SP (122 ± 17 bpm), which were statistically similar. Rating of Perceived Exertion (RPE) was highest for Fitnexx (5 ± 4 RPE) compared to TM (2 ± 1 RPE) on 0 - 10 scale. TV had lowest activity, HR, and RPE ($p < 0.04$). Given these results, AVG can increase activity levels in youth with obesity and has potential as a therapeutic tool for obese children.

KEY WORDS: Exercise program, physical activity, obesity

INTRODUCTION

Physical activity (PA) is a key stimulus for normal growth and development in children (14). The body's responses to physical activity is known to improve overall-health, including body awareness and academic performance, while decreasing the risk of many serious health conditions including obesity, heart disease, and diabetes (7, 17, 18). Despite the strong evidence for PA, physical inactivity has become a major problem among children and adolescents in the United States, with a large majority of youth not achieving current recommendation (14). Physical inactivity, along with sedentary behavior, is associated with chronic diseases such as obesity, type 2 diabetes, hypertension and others (19, 22, 45). The causes of the rise of inactivity are multifactorial, including lack of access to facilities, safety concerns, decreases in physical education in schools, and the popularity of television and video games.

One of the primary competing interests for children are videogames and electronics, which result in increases in screen time (watching television, playing computer or video games, browsing the internet, etc.). These behaviors are one of the more targeted reasons why many children and adolescents do not get the recommended amount of PA (5). Decreasing screen time is an objective of the American Academy of Pediatrics (AAP), as screen time has been associated with increased risk of obesity (2). Considering that playing video games is a popular sedentary behavior amongst children, replacing sedentary screen time (i.e. traditional video games) with active video games (AVG) (i.e. active screen time) could stimulate an increase in physical activity levels and decrease sedentary behavior in children and adolescents (41). This is especially important, as it has potential to decrease sedentary screen time that has been associated with increased risk of obesity.

For instance, some active video game platforms, such as PlayStation eye cameras and Xbox Kinect cameras, have utilized the ability to track player's movement during gameplay to control how the game is played. The amount of exertion and energy expenditure involved during a bout of exercise are contributing factors to the benefits and adaptations that occur following a given bout of activity. Promoting an active lifestyle by utilizing AVGs, also known as an exergame, could potentially provide a solution to sedentary screen time by providing a video game that can improve cardiovascular fitness, strength, balance, and flexibility as a result of game play (32, 33). Considering the enjoyable and engaging nature of video games, playing video games that are exerting to the player is critical for such technology to be effective in providing a solution to inactivity and sedentary behavior-related obesity (33). It is of importance to balance the enjoyment of a given game, while demanding enough movement from a player to stimulate a desired response to gain exercise benefits. Further, inactive individuals reported greater enjoyment with AVGs compared with traditional exercise (25, 42).

Traditional exercise prescriptions have a well-documented, positive impact on health and fitness, provided they occur at adequate intensity, duration, and frequency to stimulate a response. The dose of exercise is typically prescribed with intentional exercise selection and plans to illicit the desired outcomes. In traditional exercise programs, enjoyment and perception of success are deciding factors of the adherence to the exercise prescriptions (8, 44, 47). The type or mode of exercise has also been shown to be influential, with particular exercise modalities being perceived as more enjoyable than others. Recently, there has been tremendous interest in high intensity interval training, which has been perceived to be more enjoyable than continuous aerobic exercise, particularly in youth (6). Exercise prescriptions that result in a high adherence rate will likely have a greater impact on health and fitness. The enjoyable aspect of video games combined with the benefit of moderate and vigorous activity are fundamentally important for a successful weight management tool for children.

Early studies in AVGs showed promising results in relation to higher levels of energy expenditure when compared to sedentary video games and television watching (3, 4, 9, 12, 13, 25, 35-37). Such evidence suggests that playing AVG can stimulate greater amounts of movement as opposed to sedentary behaviors. However, there are inconsistencies in the levels of physical activity players experience during game-play. For instance, some have classified playing AVGs as light to moderate physical activity, but not vigorous (12). On the other hand, others have shown that AVGs can meet the American College of Sports Medicine guidelines for moderate to vigorous physical activity (25, 37). AVGs can be an effective weight management tool impacts on fitness-related variables, such as muscular strength, endurance, balance, and coordination (15, 20, 38).

The lack of consistency in the physical activity intensity findings are likely related to how the games are designed. Most AVGs are built on typical video game principles, which are not necessarily designed to tax the player physically. These AVGs will allow for passive advancement of the gameplay, which may require little to no movement by the player. For instance, when a game mode starts the game will continue regardless of the players input. A player can do none of the movements and still finish the game, although they do not collect as many points. This may not be enough to keep the player engaged in playing the game. However, other games with potentially more intentional focus on the player being active require the player to constantly move to advance the game or the game will pause. To our knowledge, there is no data on the impact of different story lines on physical responses. Thus, the purpose of this study is to examine the physiological responses and Ratings of Perceived Exertion of multiple different AVG storylines. The secondary aim is to document the physical activity levels and physiological responses of playing AVGs in a group of obese children as opposed to the sedentary behavior and common forms of locomotion such as TW and TM. We hypothesize that all AVG conditions will result in higher levels of movement intensity and Ratings of Perceived Exertion when compared to TM and TW. We also hypothesize that the Fitnexx exergame prototype will outperform entertainment focused games, as it was specifically intended and designed to enhance cardiovascular health, strength, balance, and flexibility of the players.

METHODS

Participants

Twenty severely obese (BMI > 95th percentile for age and sex) children aged 11-17 were recruited from their regularly scheduled visits in a referral-based, multidisciplinary pediatric weight management clinic, Healthy Lifestyle Clinic (HLC), at Le Bonheur Children's Hospital. Non-ambulatory patients or patients with physician prescribed physical restrictions were not included in this study. Patients were invited to participate in this study at a scheduled clinic visit, at which time an IRB approved informed consent form was reviewed and signed prior to participation. This project was reviewed by the Institutional Review Board and approved as a minimal risk study at University of Tennessee Health and Science Center (UTHSC). Participants received a $30 gift card as compensation for their time and transportation. This research was carried out fully in accordance to the ethical standards of the International Journal of Exercise Science (27).

Protocol

After informed consent was obtained, patients completed height measurements using a wall mounted stadiometer and weight measurements using a digital physician floor scale. All measures were collected without shoes, with a single light layer of clothing, and were repeated with repositioning between measurements. During all activities, patients wore a FDA-approved physiological monitoring system: BioHarness™3 (Zephyr Technology Corporation, Annapolis, MD, US) (16, 29). This system consists of a wireless fabric chest strap with multiple embedded sensors and transmitter unit for measuring heart rate (HR), respiration, skin temperature, body position, and activity levels.

HR is captured using conductive fabric skin electrodes made of silver lycra, which captures cardiac electrical impulses. The respiratory rate (RR) is measured with an embedded proprietary capacitive sensor composed of layers of conductive fabric, foam and flexible mylar. Respiratory Rate calculations are based on a strain gauge sensor (i.e., the resistance of a conductor is increased when the area of the conductor is increased) and chest wall expansion and contraction that cause changes in capacitance because of resultant changes in impedance (i.e. opposition of a circuit to electrical flow) (1). The change in impedance is manifested as a change in waveform signal amplitude, represented as a sine wave with downward and upward deflections indicating chest expansion (i.e. increased impedance) and contraction (i.e. decreased impedance), respectively.

Movement intensity was captured by a tri-axial accelerometer, ranging ± 16g and a collection frequency of 100 Hz, embedded within a harness (23, 28). Activity intensity (i.e. the magnitude and direction of a given movement) was measured by the velocity magnitude unit (VMU) derived from tri-axial accelerations (g) captured from axial displacement of the torso mounted harness during a given activity. This signals' magnitude vector or root sum of squares of the axial accelerations is a direct measurement of the kinematics of human movement (11, 48). The mechanical sensing elements of accelerometer-based monitors (i.e. Proof mass attached to a mechanical suspension system with respect to reference frame) allows for a direct electrical measurement of inertial forces as a result of accelerations of that deflect the proof mass according to Newton's second law of motion (11, 48). Outputs from the mechanical sensing elements are filtered to remove non-human signal artifacts and gravity. In accordance to manufacturer's specifications,~0.2g corresponds to walking activities, while ~0.8g corresponds to jogging/running (23). Such kinematic ranges are consistent with kinetic differences between walking and running at various speeds of locomotion (31). The VMU from a one-second epoch were averaged to quantify the intensity of the movement during a bout of exercise, given a collection frequency of 100 Hz. All data was relayed through a transmitter on the chest strap to transfer data to OmniSense Live software for filtration and epoch analysis. The average of one-second epochs for a duration of ten minutes was average for each condition.

A seated baseline assessment was completed first to establish a resting baseline while patients watched television (TV). This was followed by ten-minute bouts of different activities conducted in a randomized order. The activities included games controlled by the Kinect camera (River Rush, Reflex Ridge, Space Pop, and Fitnexx prototype)and Treadmill Walking (TM) (Table 1). The modified Borg scale (0 – 10) was used to assessed Rating of Perceived Exertion (RPE) every two minutes. The average from each activity was used for statistical analysis. A rest period of at least 10 minutes of seated rest between tasks was given to ensure patients were recovered to within 10% of baseline and was commenced when participants reported feeling rested. To assess the enjoyment levels, participants were asked, if they enjoyed playing the games. Additionally, we asked the participants to pick one game that they would like to play again, and inquired on additional features they wish they could have.

Table 1. Descriptions of each condition.

Condition	Condition Description
Fitnexx Prototype (Fitnexx)	Fitnexx makes players move similar to an exercise training session (high activity level that will allow for the greatest physiological adaptations). This prototype is intended to maintain engagement of the player not only by providing points, but by completely stopping storyline progression if the player does not perform the task and repetitions required to progress through the game. Game progression is dependent on the effort of the player during game play. For example, a player may have to complete 30 steps, four squats, and four alternating toe touches in order to progress to the next phase.
River Rush (RRH)	River rush is a mini-game where the player must control a raft that is traveling down winding rapids. Players control the raft by side stepping or jumping, while trying to avoid obstacles and collect as many coins as possible. In this game, storyline progression is not reliant on the player's effort during gameplay. Although the player will get more points for completing the story, the gameplay is not necessarily hindered.
Reflex Ridge (RFR)	Reflex ridge is a mini game where the player must maneuver a moving platform that is similar to a roller coaster. In Reflex Ridge, the player must jump over obstacles, side-step obstacles, squat down to avoid low beams, and jump in place to make the platform move faster. Players earn points by avoiding the obstacles and reaching for pins. Similar to River Rush, storyline progression is not reliant on the player's effort during gameplay.
Space Pop (SP)	Space Pop takes place in a virtual zero gravity environment. In Space Pop, the player can move up or down through arm movements, as well as forward or backwards by moving toward or away from the sensor. The player must pop bubbles to earn points. Similar to River Rush and Reflex Ridge, game play is not hindered or reliant on player's effort during gameplay.
Treadmill (TM)	Participants walked on the treadmill at a self-selected speed too simulate as if they are walking on a treadmill at a fitness facility or at home.
Television (TV)	Participants were instructed to sit quietly and select a television program in which they would enjoy and remain relaxed.

Kinect Adventures is a commercially available active videogame with multiple game modes driven by different storylines. These games are built for the Xbox 360 platform with the Microsoft Kinect Camera add-on. However, the release of the Kinect for Windows SDK by Microsoft enabled developer to build applications and games using standard programing language based on skeletal movement (21, 24, 39). The camera system features a high definition RGB-D camera that utilizes an infrared-laser sensor to measure depth, thus allowing for the construction of three-dimensional (3D) skeletal tracking from a depth map used to develop algorithms to detect human posture (10, 30, 40). The availability of such technology enables access for skeletal coordinates that can be used to track and drive game play in games such as River Rush (RRH), Reflex Ridge (RFR), and Space Pop (SP), and Fitnexx PC prototype that utilizes the Kinect RBG-D camera and SDK.

The Fitnexx Inc prototype utilized the skeletal tracking data to develop a game that utilizes similar movement patterns to what is used in commercial video games (e.g. jumping, squatting, leaning, stepping and other body weight activities). However, the game story and on-screen character does not move unless the player can move enough to complete the task that is required during game play. To our knowledge, the Fitnexx prototype is the first AVG game that does not allow for passive progression through the game.

Statistical Analysis

All data processing and analysis were completed in SAS 9.4 (Cary, NC). General linear models that used unstructured covariance to account for repeated measures were completed to compare activity level, HR, change in heart rate (ΔHR), RR, and RPE. Each model was adjusted for age and sex. The models for outcomes HR and RR were also adjusted using the baseline HR and RR, respectively. The residuals from each model were assessed for normality. Only the residuals from the RPE model (adjusted for sex and age) showed an extreme violation of the normal distribution. Therefore, a logarithmic transformation of RPE was used and the residuals were normally distributed [Shapiro-Wilk] ($p = 0.26$). Tukey-Kramer procedures were used to adjust for multiple comparisons. Significance was set at $p < 0.05$. Post-hoc analysis was used to evaluate individual treatment differences. Cohen's d effect sizes were also calculated for effect magnitude of condition mean differences (i.e., small: $d \leq 0.2$, moderate: $0.5 > d < 0.8$, large: $d \geq 0.8$).

RESULTS

Twenty patients (BMI 38.7 ± 7.9) completed the study (Table 2). The study included twelve (65%) male participants. Participants included fifteen African-American and five white children. All participants completed all conditions without issue. Baseline heart rate was 79.7 ± 9.1 beats per minute (bpm).

Table 2. Physical Characteristics of Participants.

Participant Number (N)	12	8	20
Gender	Male	Female	All
Age (yrs)	13.5 ± 2.4	12.9 ± 1.3	13.3 ± 2.1
Height (cm)	165.8 ± 0.1	159.6 ± 0.05	163.7 ± 0.1
Weight (kg)	108.9 ± 30.8	97.2 ± 22.4	104.8 ± 28.1
BMI (kg/m^2)	39.1 ± 8.3	38.02 ± 7.8	38.7 ± 7.9
BMI (percentile)	99.1 ± 1.52	98.2 ± 1.57	98.9 ± 1.47

Physical Activity Intensity: The Fitnexx prototype had the greatest level of movement intensity with 0.64 ± 0.15 g (mean ± SD), similar to movement intensities during running (VMU values of

~0.8g). Movement intensity during TV (0.02 ± 0.01g) was the lowest of all conditions and considered a resting activity level. The comparisons between different AVG conditions and TM (0.20 ± 0.04 g) condition reveled effect sizes ranging from small to large. Large effect sizes were observed when comparing RRH (0.29 ± 0.05 g) to TM ($p > 0.05$; $d = 2.38$). Similarly, large effect sizes were observed when comparing RFR (0.31 ± 0.07 g) and Fitnexx (0.64 ± 0.15 g) to TM condition ($p > 0.05$; $d = 1.83$) and ($p < 0.001$; $d = 3.94$), respectively. Further, when comparing SP (0.2 ± 0.05 g) to TM condition, a significant difference was observed, but with a moderate effect size ($p < 0.05$; $d = 0.21$) (Figure 1).

The VMU of measurements (g) from a chest mounted monitor was significantly higher in the Fitnexx prototype than any other condition (*Ps* < 0.0001), as well aswhen compared to TV ($d = 5.74$). TV was significantly lower than all other conditions (*Ps* < 0.0001). The comparisons between commercially available conditions (RFR, RRH, and SP) versus TV (0.02 ± 0.01g) condition revealed large effect sizes. When comparing RFR to TV ($d = 5.78$), when comparing RRH to TV ($d = 8.06$), when comparing SP to TV ($d = 5.66$). Similarly, large effect sizes were observed when comparing TV and TM conditions ($d = 5.56$). However, no statistical significance and a small effect size was observed when comparing RRH and RFR ($p > 0.05$; $d = 0.36$).

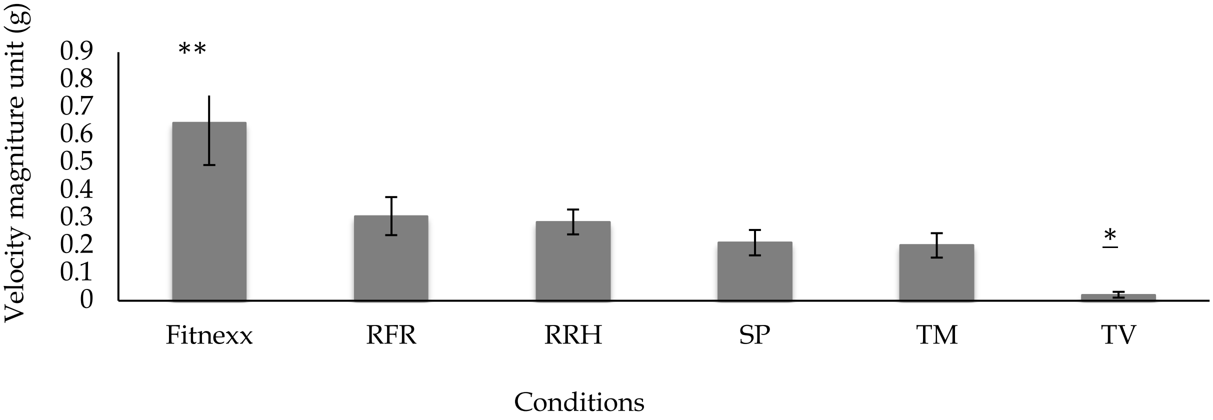

Figure 1. Velocity magnitude unit for the different test conditions. Where, RFR stands for Reflex Ridge, RRH stands for River Rush, SP stands for Space Pop, TM stands for treadmill, TV stands for television watching, and Fitnexx is the prototype developed by Fitnexx Inc (Memphis, TN). *Indicates condition is significantly lower than all other conditions. ** Indicated condition is significantly higher than all other conditions.

Heart Rate Response: Participation in the Fitnexx prototype generated the highest heart rate responses (158.2 ± 12.2 bpm) that were significantly higher than all other conditions. As expected, heart rate during TV was significantly lower than all other conditions (92.3 ± 14.9 bpm) (Figure 2). Large effect sizes were observed when comparing heart rate responses of the Fitnexx prototype to all other conditions. Similarly, large effect sizes were observed when comparing TV to all other conditions. A significant difference was observed when comparing TM (114.5 ± 19.0 bpm) to Fitnexx prototype ($p < 0.05$; $d = 2.74$). A significant difference was observed when comparing RRH (127.0 ± 18.3 bpm) to Fitnexx ($p < 0.05$; $d = 1.98$). Similarly, we observed significant differences when comparing RFR (128.0 ± 17.2 bpm) to Fitnexx prototype ($p < 0.05$; $d = 2.05$) and when comparing SP (122.0 ± 17.8 bpm) to Fitnexx prototype ($p < 0.05$; $d = 2.36$).

After controlling for age and sex, heart rate increases from baseline (ΔHR) were significantly higher in Fitnexx (66.3 ± 13.8 bpm) than all other conditions and ΔHR during TV (5.1 ± 16.5 bpm) was significantly lower than all conditions. A significant difference and a large effect size was revealed when comparing Fitnexx ΔHR to TV ΔHR ($p < 0.0001$, $d = 4.74$) (Figure 3). When comparing RRH to RFR, a small effect size and no statistical significance was observed in HR ($p > 0.05$; $d = 0.009$).

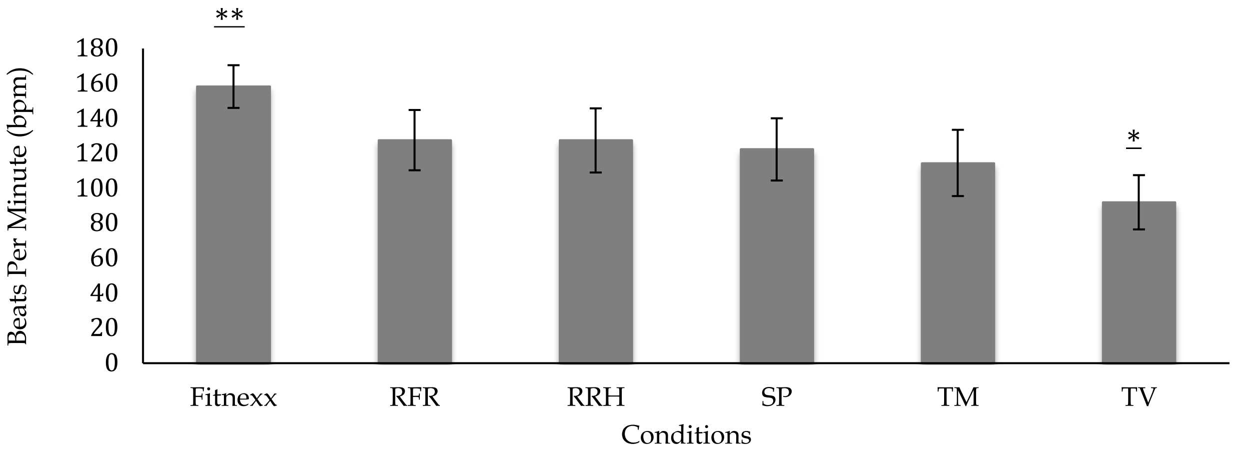

Figure 2. Heart Rate for the different test conditions. *Indicates condition is significantly lower than all other conditions. **Indicated condition is significantly higher than all other conditions. Significance was determined $p = 0.05$.

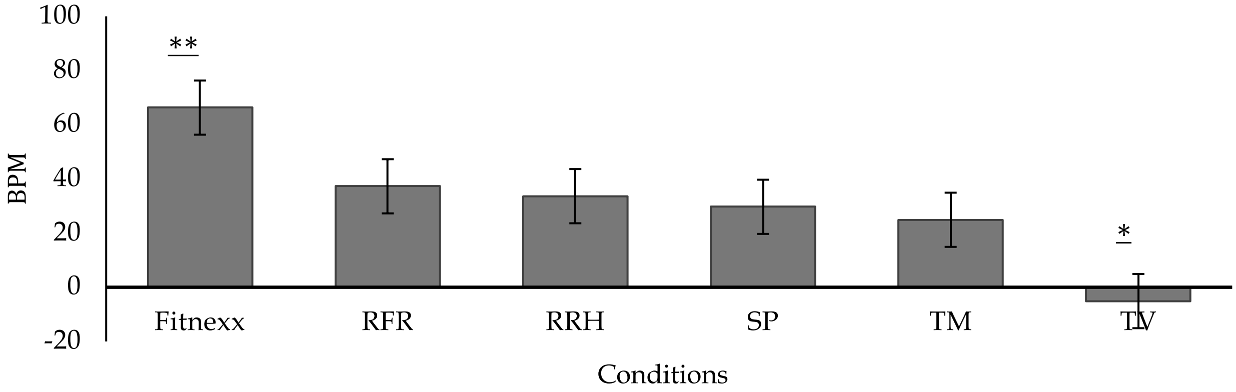

Figure 3. Change in HR for the different test conditions. *Indicates condition is significantly lower than all other conditions. **Indicated condition is significantly higher than all other conditions. Significance was determined $p = 0.05$.

Rating of Perceived Exertion: RPE for Fitnexx (5.3 ± 3.5) was significantly higher than all other conditions ($p<0.05$). RPE during TV (0.1 ± 0.4) was significantly lower than all conditions ($p<0.05$). RPE during SP (1.4 ± 1.3) was statistically similar to TM (1.5 ± 1.9) ($p > 0.05$, $d = 0.23$).

When comparing RRH (2.3 ± 1.8) to RFR (3.2 ± 2.6), no statistical significance was observed ($p > 0.05$, $d = 0.36$) (Figure 4). Patients reported greater interest and enjoyment in AVG trials than other forms of exercise.

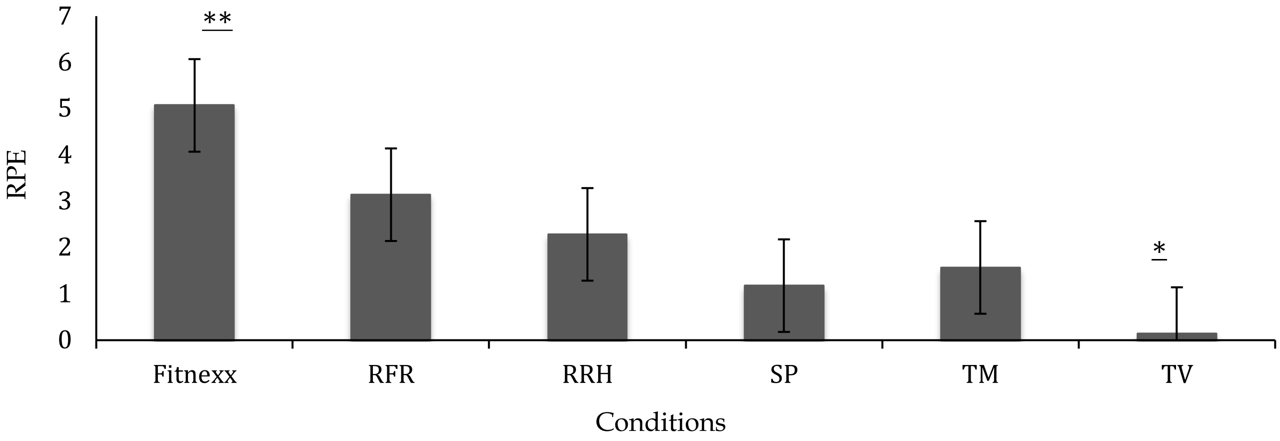

Figure 4. Rate of Perceived Exertion (RPE) for the different test conditions. *Indicates condition is significantly lower than all other conditions. **Indicated condition is significantly higher than all other conditions. Significance was determined $p = 0.05$.

Respiratory Rate Response: Respiratory rate response during TM (39.6 ± 6.5 bpm) was significantly higher than Fitnexx (28.8 ± 3.7 bpm) and represents a large effect size ($p < 0.05$; $d = 2.03$) (Figure 5). Respiratory rate response during TV (10.4 ± 5.01 bpm) was significantly lower than all conditions ($p < 0.05$). No significant difference and a large effect size was observed when comparing Respiratory Rate Response during RRH (24.8 ± 2.23 bpm) versus TM ($p < 0.05$; $d = 3.55$). Similarly, when comparing RFR (22.2 ± 2.84 bpm) and SP (24.2 ± 4.2 bpm), no significant difference and a large effect sizes were observed ($p < 0.05$; $d = 3.70$) and ($p < 0.05$; $d = 2.87$), respectively.

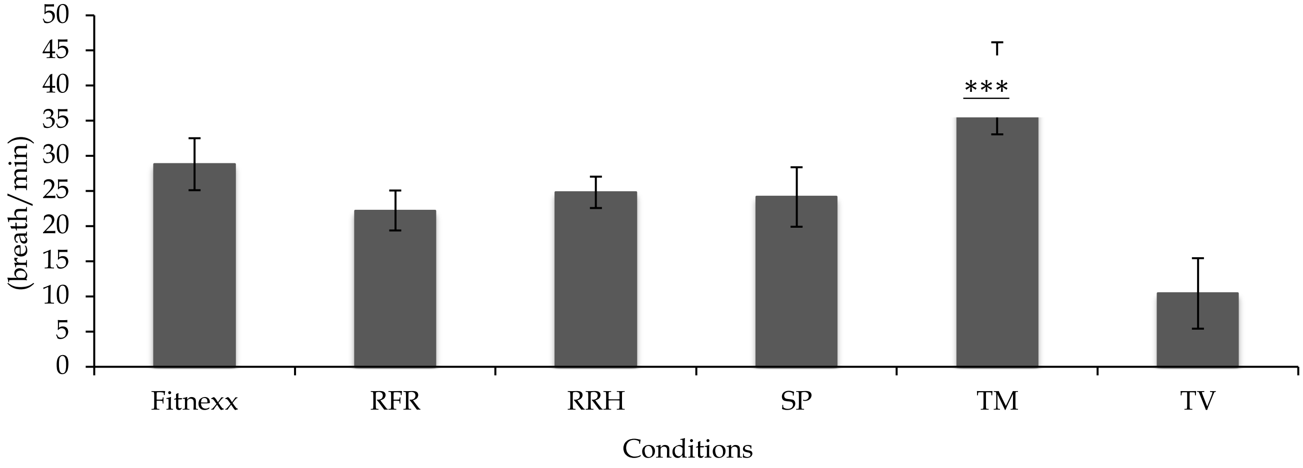

Figure 5. Respiratory Rate Response for the different test conditions.*** Significantly higher than Fitnexx. Significance was determined $p = 0.05$.

Qualitative Feedback: Participant feedback about all AVGs was positive. They reported enjoying the story lines. When asked which game they would most like to try again, participants chose the Fitnexx prototype (~50%), reflex ridge (~30%) and river rush (~20%). No participants chose to walk on the treadmill and, despite it being easier, participants felt it was the hardest to do because it was boring. When asked for suggestions about how to improve all the AVGs, the most common feedback was being able customize their character (~75%), and more advance stories/different games (~25%).

DISCUSSION

The results from this research indicate that active gaming applications are useful and effective way to accumulate physical activity. Importantly, the game play and storylines have different physiological responses and intensity of movement. In addition, games and storylines that are specifically designed to be exercise are more effective at reaching higher levels of movement intensity than games designed focusing on the gameplay.

Our results indicate that playing active videogames can be an effective way to complete a portion of the 60 minutes of physical activity per day recommended for children and young adults by the Center for Disease Control (34). Ensuring that active games are actually exerting and entertaining at the same time are important step toward developing more appealing exercise interventions for children in an attempt to balance the energy imbalances as a result of sedentary behaviors (32). The implications are particularly strong in children in health disparity areas as the video game systems, which are widely available and already present in the home, address multiple barriers to exercise experience in these households (43). Two of the prominent barriers addressed are neighborhood environmental safety and facility access (46). In regard to facility access, both membership and travel requirements are two prominently-discussed barriers to physical activity in low socioeconomic status communities. In addition, AVGs require little to no supervision from parents or caregivers, making the intervention easy without placing addition pressure on the parent to lead and motivate their child.

The story lines can play a key role in engaging and motivating the child. In typical exercise prescription, the stimulus is targeted to reach the desired outcome by manipulating variables like specific exercises, number of repetitions, and resistance/intensity. This specific strategy works well in adults and athletes, who are highly motivated and have relatively long attention spans. This approach falls short in children, who typically enjoy more game and play based options (26). Based on our findings, the game play and storylines have different physiological signatures which could lead to targeted strategies to improve specific health outcomes like motor proficiency, strength, or aerobic fitness. For example, if the goal is to improve leg strength, you might have someone do ten repetitions of squats. In the instance of AVGs, you can use the storyline to place ten objects in the path which require jumping to get over or squatting to duck under. This allows for equally prescriptive exercise therapy, but removes the dry execution of abstract exercise. We believe this an exciting first step for developing remote exercise interventions designed to improve health in children.

Our findings set the stage for further research into creative ways to use narratives and storylines to motivate movement patterns and dose of exercise to elicit adaptations. Currently, most commercially available games are designed primarily for entertainment that allows for passive progression through the game. While this does not result in high game scores, it does allow for coasting at light intensities. In contrast, the Fitnexx game condition is designed to be both entertaining and exerting with specific intention to not allow passive progression through the game. Our results showed this type of narrative gameplay results in high intensity activity. Our results lay a foundation for determining the utility of active gaming applications for intervention in children with obesity and the subsequent steps being taken in the emerging area of AVGs as medical interventions. If the predicted significantly beneficial physiologic responses are elicited, active gaming can evolve into a home exercise treatment for childhood obesity, reducing the burden of medical staff and infrastructure while providing children an innovative and active alternative to sedentary video gaming and television viewing.

The results of this study should be interpreted in the context of a couple of limitations. This study included an only a single session for each trial. While the these were randomized to minimize the impact on the results, it remains unclear if these results would be consistent over a longer duration. This study included only severely obese adolescents in a weight management clinic. It is unclear if these results would be generalizable to children without severe obesity. Finally, the study included a limited number of game modes. While these covered a spectrum of physical movement patterns, there was only one game specifically designed to be exercise. More work is needed to determine the optimal storylines and game-play. AVG design can greatly contribute to increase energy expenditure and activity levels in children and adolescents with obesity. AVG may have the potential to be used as a therapeutic tool to improve overall fitness and health of the user. Improvements in these areas could improve overall health and quality of life.

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