Evaluation of the Exertion and Motivation Factors of a Virtual Reality Exercise Game for Children with Autism

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Abstract

Children with autism experience significant positive behavioral and health benefits from exercise, though many of these children tend to lead sedentary lifestyles. Video games that incorporate physical activity, known as exergames, may help to motivate such children to engage in vigorous exercise, thus leading to more healthy lifestyles and reducing the likelihood of obesity. In this paper, we present a study of physical activity and motivation level for ten children with autism as they played an immersive virtual reality exergame that involved fast-paced full-body movement. Our results showed that most children, including non-verbal participants, were able to achieve vigorous activity levels, with several of them maintaining very high levels of exertion. Furthermore, the children reported high levels of enjoyment and indicated they would exercise more often if such games were routinely available. These encouraging findings suggest that exergames are a promising way to empower the families of children with autism with tools to help improve their child's health and quality of life.

Keywords: Virtual reality, serious games, exergames, autism

Index Terms: H.5.1 [Information Interfaces and Presentation]: Multimedia Information Systems—Artificial, augmented, and virtual realities; J.3 [Life and Medical Sciences]—Health; K.8 [Personal Computing]: General—Games

1 Introduction

Autism Spectrum Disorder (ASD) is a pervasive developmental disorder that affects interpersonal communication, social interaction, and imaginative play [23]. ASD is a spectrum disorder, which means that children range from very low-functioning to extraordinarily high-functioning, and may have drastically different experiences. Many children with autism also commonly engage in self-stimulatory behavior, such as hand-flapping, clapping, rocking, or repetitive vocalizations [18]. These sometimes chaotic behaviors interfere with the child's ability to learn, engage in positive social behaviors [26, 4, 15] and make it difficult for the child to be integrated into a mainstream educational environment [27]. Children who engage in these behaviors may be hard to reach and oblivious to external stimuli [18], making it difficult for them to learn and remain on task. The elimination or control of these behaviors may result in improvements in the child's quality of life by allowing them to improve their learning, attention, and appropriate responses to their environment [17].

Modern methods to address behavioral difficulties for children with autism include overcorrection of behavior [10] and altering the child's physical environment [8]. While these methods have been shown to be useful in reducing troublesome behavior, they require a great deal of active parental involvement, and may result in a significant amount of stress for the child. Fortunately, more recently, studies have shown that engaging in physical activity is a highly promising method of reducing self-stimulatory behaviors [22, 28, 21]. Aerobic exercise, such as jogging, is particularly effective, and can decrease self-stimulation and improve appropriate play and contingent responses[15]. However, it is important to note that mild exercise provides little to no improvements in self-stimulation, while vigorous activity is substantially effective at reducing these behaviors [14, 6, 17].

Figure 1: A child with autism playing Astrojumper using a three-wall rear-projected immersive display.

Unfortunately, many children with autism have a high risk of inactivity due to both these self-stimulatory actions as well as other behavioral and social deficits. Problems understanding social cues, making eye contact, engaging reciprocal conversation, and difficulty making friends means that children are likely to have fewer opportunities to engage in team physical activities [20]. Reduced motor control and abnormal movement patterns may also reduce opportunities for these children to participate in many athletic activities. The sedentary lifestyle of these children increases the likelihood of obesity compared with the general population, with 19% of children with autism overweight (BMI $\geq$ 95th percentile) and another 35% at risk for becoming overweight (BMI $\geq$ 85th percentile) [7]. Obesity leads to a number of serious medical issues, making it particularly important to motivate children with autism to engage in vigorous physical activity.

While exercise is certainly valuable for all children, given the unique social challenges of autism and the increased likelihood of obesity among this population, it is vitally important to motivate those that may be prone towards leading sedentary lifestyles. The marriage of physical exercise with video games, also known as exergaming, is a promising approach that has been increasing in attention and popularity in recent years [24]. Additionally, the re-

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cent release of motion sensing devices for home video game systems, most notably the Microsoft Kinect, Sony Playstation Move, and Nintendo Wii remote and balance board, has resulted in a large number of games that use body motion as a game mechanic. There is a great deal of anecdotal evidence from parents of children with autism saying that exergames are effective motivators for engaging in physical activity; however, to our knowledge, such behavior has not been formally evaluated for this specific population.

In this paper, we report a study of physical activity and motivation level for ten children with autism as they played Astrojumper, an immersive virtual reality exercise game requiring rapid body movements to dodge obstacles, collect bonuses, and fight battles (see Figure 1). This particular game has been previously studied with neurotypical children and adults, where it was shown to be an effective exercise motivator [9]. Building on this previous work, we sought to explore the application of immersive exergames for children with autism in terms of both motivational and physiological effectiveness. To the authors' knowledge, this is the first full-body exercise game that has been formally evaluated with children with autism. Our results demonstrate that exergames are a promising method for engaging children with autism, and we argue that leveraging video game technology as an intervention has the potential to address many behavioral and health problems commonly associated with this population.

2 Previous Work

The introduction of motion sensing hardware to popular video game platforms has resulted in numerous commercial titles that use physical activity as a game mechanic (e.g. Wii Sports, Kinect Sports). However, most commercially developed motion-based video games are designed primarily for entertainment purposes, and thus it is often possible for users to "game the system." For example, while the Nintendo Wii allows players to engage in realistic motions such as swinging a tennis racket, it does not require accurate and realistic behavior, as frustrated players observe when they are beaten by an opponent who was sitting on the couch flicking their wrist. There is evidence that exergames can get neurotypical users to engage in more physical activity than they would with a typical video game; however, these users only barely reach moderate exercise levels during gameplay and generally don't approach the vigorous activity levels needed for exercise to be effective [11, 12]. Several commercial titles have been introduced specifically to promote weight loss and fitness (e.g. Wii Fit, The Biggest Loser Ultimate Workout), but these are typically designed for adults, and it is unclear whether they would be able to successfully engage children, especially those with developmental disorders.

Exergames require carefully designed game mechanics that balance the psychological flow of gameplay (entertainment) with the physiological flow of exercise (exertion) [24]. Successfully balancing these two considerations is challenging, a fact that is supported by previous evaluations of commercial exergame interfaces from the literature. For example, Luke et al. analyzed energy expenditure in a variety of exergames using the Sony EyeToy, and found that users largely engaged in only small bursts of exercise followed by long pauses, preventing their heart rate from building [19]. Smith noted similar problems during a personal analysis of three video game extertion interfaces, finding large variability in exertion between games and difficulty maintaining an elevated heart rate due pauses caused by load times [25]. While playing commercial exergames is surely better than engaging in no physical activity at all, these findings suggest that such games that are designed primarily for entertainment value may not be effective at inducing the exertion levels required for a vigorous workout.

Several exergames have been developed by the research community to specifically engage children in physical activity. One such application is Bug-Smasher, which uses a tiled grid interface with randomly-appearing colored lights that engage the child to jump around and "smash bugs" [29]. Interestingly, the authors found that children who projected their fantasies into the game world reported higher levels of enjoyment. In an attempt to leverage such imaginative fantasies in real world play, Bekker et al. presented two case studies with interactive physical props that stimulated open-ended gameplay requiring body motion [5]. One example of an interactive video game to engage children in physical activity is QuiQui, which was developed to gather data on the intuitive body motions that children employed when attempting to control a game character [13]. Performing user tests with a Wizard of Oz approach as well as a functional vision-based prototype, they found that patterns in children's intuitive motions could be used to improve vision algorithms and avatar animations for exergames. Additionally, noting that game development tends to focus on the upper body due to technical constraints, they suggest that future game designs should aim to provide more holistic full-body motions such as running and jumping. However, none of these games included evaluations of the physical exertion levels that children attained during gameplay.

3 Study Design

While Astrojumper has been shown to be effective in engaging neurotypical children and adults in vigorous, full-body exercise [9], it is unclear whether it would also be effective in motivating children with autism. Since we could not find any published work that presented exergame design considerations for children with developmental disorders, we sought to evaluate how well the game motivates such children to engage in physical activity at the exertion level and duration recommended by exercise experts.

3.1 Participants

We recruited ten participants primarily through interactions with local chapters of autism groups such as Autism Speaks and The Autism Society of North Carolina. The participants were invited to come to our lab with their parent for two separate sessions about a week apart. Participants ranged from ages 8 - 20, (M=12.60, SD=4.09), with the majority of participants between 8 and 13. Two of our participants were older (ages 18 and 20) and were also nonverbal, meaning that they were able to understand and follow directions, but were not able to communicate through verbal language. These two participants also were not able to type, so they did not fill out the post-experiment questionnaire. Their parents filled out the objective information that they knew on the pre-experiment questionnaire. Participants ranged from moderately low-functioning to very high-functioning, with two diagnosed with Asperger's Syndrome. This is a type of autism where affected individuals are usually quite high-functioning with either average or above-average intelligence and none of language delays as a young child that are characteristic of most children with autism.

3.2 System Overview

When playing Astrojumper, the user flies through an outer space environment with a first-person perspective, avoiding planets by dodging, ducking, and jumping. Points are accumulated automatically over time so long as the user avoids colliding with an obstacle. A base rate of one point per second is added, though this rate can be increased by collecting golden suns to add bonus score multipliers. In the event of a collision with any part of the player's body, the score is temporarily frozen, and any previously collected bonus score multipliers are reset. The game also features periodic UFO battles, where an alien ship appears and begins shooting red laser beams at the player. To defeat the UFO, the user must dodge these beams while shooting green lasers through strong throwing or punching motions.

Following the American College of Sports Medicine's guidelines for exercise [2], Astrojumper's gameplay is divided into three phases: (1) a warm-up phase with gradual increases in speed, (2) an exertion phase requiring continuous vigorous physical activity, and (3) a cool-down phase that allows a gradual decrese in effort. To balance entertainment with physical exertion, the difficulty of the game is dynamically adjusted based on the player's performance. This adaptation ensures that gameplay will not become trivially easy or impossibly difficult for different players with varying levels of physical fitness. More details on Astrojumper's design philosophy and characteristics can be found in the previous work [9].

We deployed Astrojumper on an immersive surround-screen display system comprising three 2.44m x 1.83m rear-projected stereoscopic screens, each of which used two Barco Gemini projectors to display the images for each eye. Circularly polarized glasses were worn on the user's head, with a Polhemus Fastrak electromagnetic sensor attached to the rim of the glasses. Two more trackers were enclosed in sweatbands on the user's wrist, and a fourth tracker was attached to the bottom of a small backpack to track the waist. All cables were routed through the backpack to allow the user to move freely without getting tangled. Physiological data was collected during gameplay using a BodyMedia SenseWear armband. The game software was run on a quad core Intel Core i7 3.33GHz PC with 12GB of RAM, and a total of three NVIDIA GTX 260 graphics cards provided output for all six projectors.

3.3 Procedure

Participants were invited to come to the laboratory for two separate sessions spaced about a week apart, each of which took approximately 45 minutes to complete. In one session, participants played the game in a three-screen surround configuration. In the other session, only the front screen of the immersive display was used, and the two side screens remained off. The order of presentation for the sessions was counterbalanced across the study.

On the first visit, participants and their parents were given informed consent sheets, and the experimenter spoke directly to the child about what they would be doing in the study and the families were given the opportunity to ask questions. In addition to obtaining consent from the parents, assent was also obtained from the child, with communication assistance from the parents when needed. Following that, the child and their parent completed a demographic survey, and the child's height and weight were collected for computation of physiological measures. The child was then fitted with the tracking equipment and exercise armband, and the rules of the game were explained. We initially displayed a static virtual world on the projection screens until the child was comfortable, followed by a two minute practice game that remained relatively slow and easy. After the practice ended, we encouraged the child to ask questions and offered gameplay advice if we noticed that the child seemed to be not fully understanding. The child then played a 15 minute game session including the warm-up, exertion, and cool down phases. After completing the game, participants completed a post-experiment questionnaire, and the session concluded. On the second visit to the lab, the experimenter pointed out that the system was a little different from the last time, having either two more or two less screens than the previous session. The child then followed the same procedure as the first session, followed by a short final survey to compare both versions of the game display (three screen vs. single screen).

3.4 Measures

Demographic survey The demographic survey collected information on the child's age, ethnicity, video game habits, and type of Autism Spectrum Disorder the child was diagnosed with. It also collected information on the child's movement patterns using the Body Use index from the Behavior-Disturbed Children (Autism) Questionnaire, identifying whether or not the child engages in "age appropriate body use", "mildly abnormal body use", "moderately abnormal body use", "severely abnormal body use," or somewhere between any two of these categories [1]. The parents of our two non-verbal participants filled out as much of the survey as the could for their children, however, subjective responses that these parents could not accurately report were not included in our analysis.

Physiological Measures The BodyMedia SenseWear armband recorded the participants' metabaloic equivalent (MET) during gameplay, which is defined as the amount of oxygen consumed while sitting at rest. The MET concept represents a simple, practical, and easily understood procedure for expressing the energy cost of physical activities as a multiple of the resting metabolic rate. For our analyses, we used the standard breakdown for classifying activity levels: activity under 4 METs was considered light-intensity, activity between 4 and 6 METs was considered moderate-intensity, and anything 6 METs or above was considered high-intensity or vigorous activity [16]. While we were initially concerned that children with autism would have issues wearing the armband, none of our participants complained or indicated discomfort as a result of the device. The armband reported the following measures: (1) the participant's average MET level throughout the gameplay session, (2) the number of calories burned, (3) and the number of minutes spent in vigorous exercise. Because research indicates that vigorous exercise is most successful at reducing self-stimulatory behavior in children with autism, we were very interested in observing the amount of time that participants spent exercising at or above 6 METs while playing Astrojumper.

Post-experiment questionnaire Participants filled out a questionnaire at the end of both of their gameplay sessions, which included ratings on a 7-point scale regarding enjoyment, replayabilty, and amount of exercise. We also collected ratings on what aspects of Astrojumper were most fun for the participants (1="much less fun," 4="same amount of fun," 7="much more fun"). Specifically, they were asked to consider the following: (1) if Astrojumper wasn't in stereoscopic 3D, (2) if they didn't need to run around to play, (3) if they needed to hold controllers, and (4) if they were playing on a smaller screen. After their second exposure, they were also asked to rate whether they preferred the one-screen or three-screen version of the game in terms of fun, motivation, and amount of exercise (1="strongly one-screen" to 7="strongly three-screen").

4 Results

4.1 Demographic information

Most participants did not have very severe body movement impairments, with all participants' parents marking that their child was between a "1" (completely age-appropriate body control, child has the same ease, agility, and coordination of a neurotypical child) and "3" (moderately abnormal body use, including strange finger movements, peculiar body posturing, self-directed aggression, rocking, spinning, finger-wiggling, or toe-walking), (M = 2.00, SD = 0.82). Participants universally rated that they enjoyed video games a great deal, with no one selecting lower than a 6 out of 7 (M = 6.83, SD = 0.33). We had one outlier, our lowest-functioning participant, whose parent reported that he played video games approximately 60 hours per week. The remaining participants reported that they played video games between 3 and 15 hours per week, (M = 9.67, SD = 4.44).

Participant responses (1-7) on questions pertaining to exercise enjoyment did not indicate preferences towards physical activity , such as"I engage in physical activity whenever I can" and "I feel uneasy when it comes to doing strenuous physical exercise" (reversed), (M = 4.43, SD = 1.53). We found similar results on questions about perceived exercise competence, including "I'm better at sports than other kids my age" and "I don't do too well at outside games" (reversed), (M = 4.20, SD = 1.81). We found a positive

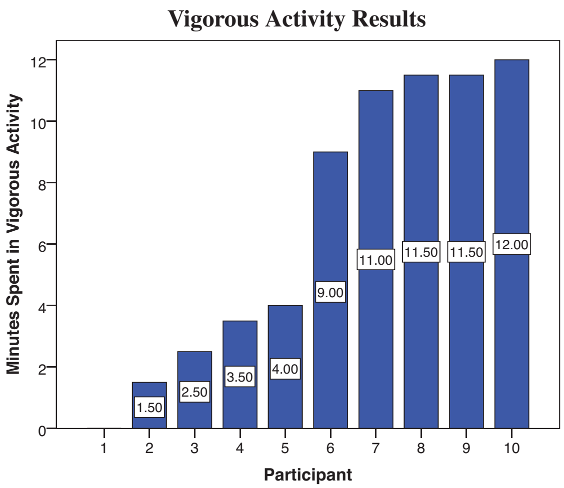

Figure 2: The amount of time spent in vigorous activity (MET level of 6 or greater) for each participant. Since the warm-up and cool-down phases each lasted 2.5 minutes, 11-12 minutes of vigorous exercise is about the maximum possible time one could have reasonably spent vigorously exercising during the 15 minute session.

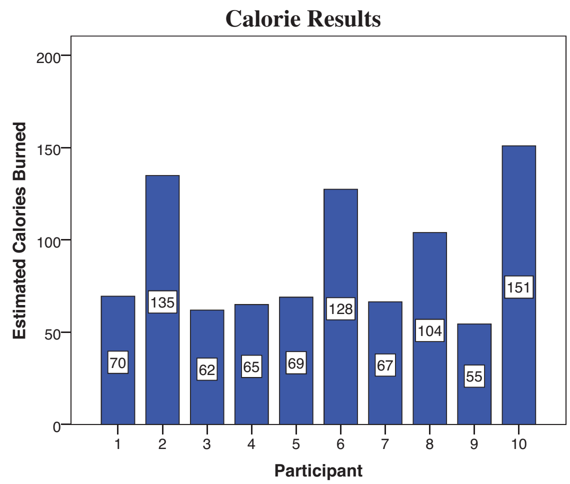

Figure 3: The total estimated calories burned by participants.

correlation between participants' ratings of exercise enjoyment and perceived competence, $r(10) = +.86$, $p < .01$.

4.2 Physiological measures

Participants' physiological measures were calculated by the Sensewear armband that took the participant's age, height, and weight into consideration. We found no significant differences between the screen conditions or first/second exposure to the game, so we averaged the physiological data across the two sessions.

Participants spent an average of 6.65 minutes ($SD = 4.77$) out of the 15 minute game session engaging in vigorous exercise (i.e. at MET levels of 6 or greater). However, as demonstrated in Figure 2, there was a large amount of variance in the amount of time between participants, with the children roughly falling into two groups. Half of the participants spent the majority of the game session in the vigorous zone, with four of them spending 11 minutes or more. This is especially encouraging because the warm-up and cool-down phases each lasted 2.5 minutes, meaning that 11-12 minutes of vigorous exercise is about the maximum possible time one would have reasonably spent vigorously exercising out of the 15 minute session. However, the other five participants spent less four or less minutes in the vigorous zone, with one participant never peaking above moderate activity.

Participants' average MET levels over the entire gameplay session were at moderate levels ($M = 5.07$, $SD = 1.24$). However, this is not the most informative measurement, because that included time spent in the warm-up and cool-down phases, when they would not be expected to be exercising vigorously. It is more useful to observe the total calories estimated to have been burned during a game session ($M = 90.39$, $SD = 35.62$). We observed a large amount of variation in caloric expenditure between individuals, but this is to be expected since it is highly dependent on the participant's physical fitness. However, as shown in Figure 3, all the participants that spent less time in the vigorous zone managed to burn upwards of 60 calories during the 15 minute session.

4.3 Post-experiment questionnaire

Participants filled out this survey at the conclusion of both their first and second exposure to Astrojumper. Again, we found no significant differences between the screen conditions or first/second exposure to the game, so we analyzed the average of each participant's ratings (1-7) across the two sessions. Our post-experiment survey results were very positive, with participants reporting that they greatly enjoyed playing Astrojumper ($M = 6.63$, $SD = 1.06$) and that they would exercise more often if they could play Astrojumper whenever they wanted ($M = 6.00$, $SD = 1.00$). Participants also reported moderately high scores when asked if they got a good workout ($M = 5.38$, $SD = 1.16$), though this self-perception was not correlated with the amount of time the player actually spent engaging in vigorous activity. Astrojumper was rated as slightly more exercise than they would usually get ($M = 4.94$, $SD = 1.15$).

We received very encouraging results regarding replayability, as this aspect is very important in maintaining long-term exercise goals with video games. Participants reported that they would be very likely to play Astrojumper once a week or more if they could, ($M = 6.38$, $SD = 0.88$). Additionally, we found extremely low reports regarding both whether the participants thought Astrojumper was boring ($M = 1.38$, $SD = 1.06$) and how likely it would be that they got bored of Astrojumper eventually ($M = 2.18$, $SD = 1.65$). Participants also indicated that they would be interested in coming back to the lab to play Astrojumper a third time, even if it wouldn't be part of the study ($M = 6.19$, $SD = 1.19$.)

Participants also generally indicated that the immersive, full-body aspects of the game contribution to their enjoyment (1="much less fun" to 7="much more fun"). Participants indicated that playing on a smaller screen would most strongly make the game less fun ($M = 1.25$, $SD = .378$) and as would removing the stereoscopic 3D effect ($M = 1.69$, $SD = 1.03$). Participants also indicated that the game would be less fun if they didn't need to move around to play ($M = 2.00$, $SD = 1.20$). When asked their preference regarding the single-screen vs. the three-screen setup, all but one participant indicated that they preferred playing with three screens. The one player who selected the single screen condition stated that he found the side screens distracting.

4.4 Qualitative feedback and observations

As some of our participants were more low-functioning, our qualitative observations may be more indicative than their responses on questionnaires. Many of the subjects seemed to be projecting fantasies during gameplay. This included expressions such as "Alert! Alert! We have the aliens on the loose! They will get me, they will get me!", and "I have lasers, magical - magical lasers and they will - and I'm gonna, and I'm gonna punch those aliens out of here, oh yeah!" Two participants excitedly told their parents and the experimenters that they felt like comic book characters, and described (in great detail) how they could use their powers from Astrojumper to "destroy bad guys." All but one of the participants laughed as they threw their lasers, and most cheered when they beat the UFO.

While seven of our participants exhibited only slightly impaired movement patterns, three engaged in constant self-stimulatory behavior, including hand-flapping and rocking, as well as other characteristic behaviors such as toe-walking. These three participants in particular had difficulty making the punching motion necessary to shoot the laser. We intentionally designed it so that the laser was only triggered by a controlled forward throw. As we hoped, by their third exposure to the UFO on their first trial, these three participants began being able to consistently do this motion. By the end of the second session, these participants were able to make this motion almost, if not as well as, other participants. We were particularly inspired by our lowest-functioning non-verbal participants who were able to play the game very well, one of which even earning the top score out of all participants. One of the parents stated that she was moved to see her child so clearly engaged and excited by something new, and that she was very happy to see him exercising.

The most common comment from participants was that they liked being able to control the game with their body. One child explained "I am the controller, so I need to move myself to get the game to work. If I'm lazy the game won't work at all so I need to move around." Participants also often described the sense of presence they felt in the game. One child who was able to communicate, though not in full sentences, said multiple times that Astrojumper was beautiful and that he "could look at the stars [in the game] all day." A few of the higher-functioning participants provided detailed descriptions of plot they would like in the game - in many cases, plot that their parents confirmed had something to do with their special interest. One child spent a great deal of time playing an outer space video game, and had clearly been projecting memories and thoughts about this game into his Astrojumper experience. One child's special interest was Marvel comics, and he spoke extensively about all of the different superheroes he was pretending to be while he played. Another child spent most of his free time watching the Star Wars movies, and would hum / sing the tunes and call out to characters from the movies throughout gameplay. While these were the only three participants that we identified as integrating their special interest into the game, most other participants frequently vocalized general cries of excitement ("Oh! Get him!" or "I got it!"). A few of others used the post-experiment questionnaire to describe how they would have liked to improve their game - often involving their special interest. For example, one participant who listed "cartoons" as his special interest recommended that Scooby and Shaggy from the cartoon series Scooby Doo should be included in future versions of Astrojumper. This is consistent among children who listed special interests - the child who loved Nascar recommended that the game include race cars, and the child who was very interested in zombie mythology said there should have been enemy zombies present in the game. The participants who either did not list a special interest or listed more general things like "reading" or "Wikipedia" did not recommend any changes to the game that altered content, instead commenting that "there should be more UFOs to shoot" and "I want to be able to shoot the planets with lasers too."

5 Discussion

While playing Astrojumper, all but one of our participants achieved vigorous physical activity for at least 1.5 minutes, half of our participants spent the majority of gameplay in vigorous activity, and a few even spent the maximum amount of time possible vigorously exercising, given the inclusion of warm-up and cool-down phases. Additionally, all participants, even the ones who spent smaller amounts of time in the vigorous zone, were estimated to have burned a decent number of calories during the 15 minute session. We found these results very encouraging, and were particularly motivated by the participants high ratings of their own enjoyment from the exergame and their belief that they would exercise more if they could play games like Astrojumper whenever they wanted. It is important to note that the two non-verbal participants were not able to provide feedback, and some of the children received parental assistance in filling out questionnaires, so we should be cautious about over-generalizing the findings from the self-reported data. However, our qualitative observations indicated that even the low functioning and non-verbal children seemed motivate to engage with the game physically. Since research indicates that vigorous exercise is the most effective way to reduce self-stimulatory behaviors in children with autism, we believe that further development and evaluation of exercise games is needed for this population.

At the time we ran this study, the Microsoft Kinect had not yet been released, and participants made comments about how this game wouldn't be as fun on the Wii because they couldn't control the game using their body. Given that low-cost full-body tracking devices such as the Kinect are now commonly available for home video game consoles, we believe there is great potential for integrating exergames into the daily routines of children with autism, as well as neurotypical children. Additionally, while an immersive surround-screen environment is not a setup that people typically have in their homes, our results found that this level of immersion doesn't increase the level of vigorous activity of our participants. Even so, large televisions, wall projectors, and even 3D stereoscopic screens are becoming increasingly common. Such home equipment could allow for gameplay that approaches the immersion level achieved in our lab in our single-screen condition. As such, we have also created a version of Astrojumper that works with a Kinect on the user's home PC, and we are planning to make it available for download in the near future. While we have not evaluated the Kinect version of this game formally on children with disabilities or neurotypical children, initial playtesting in our lab indicates that this version is just as engaging and promotes as much vigorous activity as the version we deployed on our VR system. In future work, we will conduct user studies to examine differences in motivation and vigorous exercise between our expensive VR system and more widely available low-cost systems such as the Kinect.

Looking at the children's interests in athletics, we found that the participants who felt they were not as good at sports as their peers tended to engage in more solitary activities such as swimming or bowling. However, those that had more confidence in their athletic competence participated in team sports. Additionally, we found a correlation between how confident the participants were in their athletic ability and how much they enjoyed exercise. While we do not have enough information to infer causation and we are dealing with a small sample size, we believe that making exercise fun might be a reasonable first step towards improving a child's confidence in their physical ability. Based on the results from our study, we suggest that video games are a promising way to achieve this goal.

Astrojumper was specifically designed with a space theme because it is a common special interest cited by families of children with autism. One of our most notable observations was that the participants who had listed special interests that somehow paralleled aspects of Astrojumper (Star Wars, super heroes, and a different space-themed video game) made vocalizations during gameplay that indicated the child was projecting parts of those interests into Astrojumper. Additionally, the children who listed concrete special interests entirely unrelated to Astrojumper, such as race cars, cartoons, and zombies, said that the game would have been more fun if it included those elements in the design. Children with autism typically have a great deal of perseverence with their special interest, and their particular interest can remain the driving force in the child's life. There is a great deal of anecdotal evidence from teachers who recommend letting children with autism pick their own topic for their writing and learning assignments, harnessing the child's interest to increase excitement about schoolwork. These numerous accounts have been corroborated by studies showing that children with autism improve their social behaviors when the play environment includes their special interest [3]. Therefore, we suggest that leveraging special interests may be a valuable design mechanic for exergames that need to maintain the child's interest even after repeated exposure. Given the variability in these interests, it is not practical to custom-build games tailored perfectly for each child's particular interest. However, it may be possible to create a general game design that contains multiple content themes and image sets that the child can choose from, such as dinosaurs, trains, sharks, astrology, etc. Another very promising possibility would be creating an intuitive interface that would allow the child or the child's family to upload some of his or her favorite images to customize the look and feel of the exergame.

6 Conclusion and Future Work

In this paper, we presented a study of physical activity and motivation level for ten children with autism as they played an immersive virtual reality exergame. Our results showed that most participants were able to achieve vigorous exercise, and many of them maintained high levels of exertion for the majority of game time. Furthermore, feedback from participants was highly promising, with many children indicating that they would like to play the game again. In the future, we plan to conduct longitudinal studies of the long-term effectiveness of exergames in motivating children with autism to make lifestyle changes that incorporate vigorous physical exercise. Recent advancements in display and video game tracking technology make it feasible to consider deploying such full-body exergames in home scenarios, thus empowering families of children with autism or other developmental disorders with the tools to help them improve their child's health and quality of life.

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