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REGULAR ARTICLE

Efficacy of Online Multi-Player Versus Single-Player Exergames on Adherence Behaviors Among Children: A Nonrandomized Control Trial

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Abstract

Background Exergames have the potential to significantly increase physical activity in children. Studies to date have shown mixed results and often rely on self-reported data. Multi-player gaming may augment participation.

Purpose The purpose of the study was to examine children's adherence behaviors in multi-player online exergames compared to a single-player condition within a home environment.

Methods Seventy-two children, aged 9–12 years, who were not meeting physical activity guidelines at baseline, were allocated to the multi-player or single-player condition. Six-week cycle-based exergaming trials took place 5 day/week in the early evening with online game supervision. Bike use was objectively recorded via game logs.

Results Adherence was high throughout the trial. Play session duration was $M = 37.65$ ($SD = 15.39$) min/day, and overall play duration was $M = 133.45$ ($SD = 81.27$) min in Week 1 and $M = 77.23$ ($SD = 84.09$) min in Week 6. Total physical activity was significantly higher at 6 weeks compared to baseline ($p = .01$, $\eta_p^2 = .13$). There was no significant difference in play duration between conditions ($p = .57$, $\eta_p^2 = .01$).

Conclusion This trial objectively demonstrated that exergames can promote high adherence levels. Multi-player capabilities did not augment adherence levels. Introducing new games throughout the trial may have motivated participants to keep playing, regardless of whether play was against real or artificial opponents. Weekly play duration decreased due to a significant drop in play frequency. For children who enjoy exergames, innovative solutions to promote more frequent exergame play are needed.

Clinical This Registration NCT02032667.

Keywords Exergame • Adherence • Multi-player • Children • Home environment • Nonrandomized control trial

Introduction

Physical activity is of great importance to children's health, but fewer than 10% of Canadian children meet the recommended 60 min per day of moderate-to-vigorous physical activity (MVPA) [1]. However, children do spend a large amount of time in front of a television, computer monitor, or cell phone. For example, Canadian children have been reported to spend 7.8 ± 2.3 h on average per day in front of a screen in three activities: watching TV or videos ($M = 3.0 \pm 0.9$ h/day), playing video games ($M = 2.1 \pm 1.1$ h/day), and playing or

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surfing the Internet on a computer ($M = 2.9 \pm 1.1$ h/day) [2]. Passive screen-based activities such as these have been associated with a decline in physical fitness among children [3, 4].

Given that children already play digital games and spend a large portion of their time in front of a screen, it would be beneficial to turn some of this passive screen-watching into active play by incorporating physical activity in games. Active video games, also known as exergames, have been developed for this purpose. Exergames are games that require physical exertion to play [5–7]. Exergames elicit greater energy expenditure when compared with rest and nonactive video games [8], but they may not elicit as high expenditure as outdoor activities and sports [9]. This energy expenditure is typically in the light-to-moderate intensity range [10], which has been associated with marked reductions in the risk for mortality and chronic disease [11].

Exergames have been shown to be enjoyable [5, 6, 12]. They also provide an inexpensive and safe activity that can overcome barriers to physical activity, such as inclement weather and parents' fears about outdoor neighborhood play, since exergames are typically played indoors [13]. But, some people question the role of exergames in promoting physical activity since they are a screen-based form of entertainment [14, 15]. However, researchers have demonstrated that exergames can lead to significant health benefits [16–18]. They have also been shown to provide benefits beyond promoting physical activity, such as improving fundamental motor skills [19]. This may be because motivation for exergame play behavior is based on affective expectations (e.g., how much you think you will like the exergame). Affective expectations play a central role in many health behavior models, including self-determination theory, the theory of planned behavior, and social cognitive theory, all of which show a clear link to physical activity in children [13]. Since exergames have been shown to be engaging, they may be considered useful additions to promoting physical activity in children despite being a screen-based activity [13].

Critiques of exergames are that total play duration quickly wanes after the novelty of the game has worn off, and play sessions are short in duration, in the range of 5–10 min of play [20–22]. For instance, in a 6-month intervention study, Madsen et al. reported declining exergame usage [20, 23]. Between Months 3 and 6, only 2 of the 21 children who submitted a play log reported using the exergame twice per week or more, despite being provided with instructions to play the game 30 min per day, 5 days per week [20, 23]. Self-reported play duration in Madsen et al.'s trial also demonstrated low amounts of activity. The trial started with participants reporting approximately 12 min of play per day, and by Month 6, self-reported play duration decreased to 7 min per day [23]. In another intervention study, Maddison et al. suggested that playing exergames for at least 30 min per day could lead to lower body weight, but they only measured participants' energy expenditure for 5–8 min of play [24]. Given the low play durations reported in previous trials, it is possible that children may not be willing to engage in exergames for sufficient time to accrue health benefits [20].

Several potential strategies exist to increase play duration and frequency in exergames. One method is to introduce different games throughout the trial to sustain the novelty of play [22]. Another approach is to include more gamified components (e.g., incentives like enhancing character abilities and purchasing costumes for avatars) embedded in the exergame. A third method is to incorporate multi-player capabilities because they encourage cooperation and competition [25]. There is evidence to suggest people are more likely to sustain their involvement in a physical activity setting if they participate in social, or group-based, activities rather than on their own [26–29]. Multi-player aspects have also been a large part of the success of games in general [30–32]. For instance, massively multiplayer online games such as Blizzard's World of Warcraft are played by millions of people [33]. Numerous authors have advocated incorporating social play in exergames to foster interaction and increase motivation [34–37]. In fact, supporting social play is considered a core component of exergame design and has led to the design of several successful exergames [21, 38, 39]. To date, though, there has been little research comparing multi-player and single-player exergame duration.

In one of the few attempts to explore this issue, Chin A Paw et al. [21], performed a pilot study that randomly assigned 27 children to either a single-player group that played a dance game at home or a multi-player group that played the game at home but also participated in a weekly multi-player class. They found no statistically significant difference between the self-reported play duration between groups, but the multi-player group played over twice as many minutes as the single-player group over a 12-week period (901 min vs. 376 min, $p = .13$). Dropout was significantly different between groups, favoring the multi-player group (15% dropout rate) over the single-player group (64% dropout rate). Limitations included a small sample size and the self-reported measures of game play that were operationalized in this study.

Indeed, as a broad critique of studies in this area, exergame trials involving children have generally suffered from a limitation of measuring play duration through self-reported methods [22, 23, 40, 41]. For instance, Graves et al. and Mhurchu et al. compared play duration between children that received either an active video game package or no intervention. Play duration was estimated via self-report using activity logs [22, 40].

In each of these studies, control groups were given no active video games, but self-reported play duration data indicated high levels of active video game play. For instance, Graves et al. stated that active video gaming for the control group at baseline was about an hour per day [22]. Given the control groups were not given active video games to play, it is unclear what games the control groups were playing. The active video game play duration also seems high, which is likely due to limitations of using self-reported data.

We conducted a two-arm, nonrandomized control trial that compared a multi-player suite of mini-games, Liberi [5, 38, 39], to a single-player version of the games in a home environment (see Fig. 1). The trial was designed to overcome the limitation of using self-reported data by using objective measures. The study had three primary outcome measures, each objectively measured using game play logs that recorded activity for every second the game was loaded. Current guidelines suggest children participate in 60 min of daily MVPA [42], and exergame play sessions have been critiqued for being too short in duration to provide health benefits, typically ranging from 5–10 min [20]. Therefore, our first primary outcome was mean play session duration, our second primary outcome measure was weekly play duration, and our third primary outcome measure was play frequency. We had two secondary measures, play intensity and total physical activity. Play intensity was measured by recording heart rate during gameplay. Total physical activity was recorded via self-report. Since Liberi included a central area outside of the mini-games that afforded players the opportunity to be idle or relax, inactive play duration was measured as an exploratory outcome.

Consistent with prior research, we hypothesized that for both conditions, mean play session duration and overall play duration would wane over time [20–22], and play intensity would be in the light-to-moderate range [10]. However, we hypothesized that the social aspects embedded within the multi-player condition, which were designed to foster enjoyment and motivation, would lead to significant differences between conditions. We hypothesized that the engaging aspects of the multi-player condition would encourage longer and more frequent play than in the single-player condition. We had no a priori hypothesis regarding group play intensity differences. Competitive and cooperative play in the games could have promoted higher intensity levels in the multi-player group, but socializing with others could have just as easily become a more prominent focus than playing the games at moderate-to-vigorous intensity levels. Since physical activity was measured using self-reported data, we had no a priori hypothesis regarding total physical activity. We also had no a priori hypothesis regarding inactive play duration.

Materials and Methods

Inclusion Criteria

Eligibility criteria included having at least one parent/guardian over 18 years of age willing to participate in

Fig. 1 (A) Two of Liberi's mini-games, Gekku Race (top) and Dozo Quest (bottom)[5]. (B) Equipment used to play Liberi.

the study, being between 9 and 12 years old, not meeting physical activity guidelines as outlined by the Canadian Society for Exercise Physiology [42], not having a developmental disorder or disability, and having high-speed Internet access. Compliance with current guidelines was determined by parent self-report during recruitment, and child self-report during the study. Children aged 9–12 were chosen because this is an age in which children can physically use the bikes [43]. In addition, games were designed for a late elementary school level and might not be as suitable for a mature audience.

Recruitment

Participants were recruited using advertisements placed at elementary/middle schools, cub scouts/brownies, recreation centers, health care centers, children's recreation classes, shopping malls, and online sites Facebook and Kijiji. We also recruited through snowball sampling, in which families of previous participants were offered a $25 CAD honorarium.

Design

The study consisted of five waves of 6-week trials in two mid-size cities in Canada, Kingston, Ontario and Victoria, British Columbia. The five waves of trials ran from January 2014 to December 2014. The trial employed a two-arm, nonrandomized control trial design. Assessors were not blinded, and due to the characteristics of the study, participants and care givers were not blinded to study condition. Participants were blinded to the fact that there was a second condition being studied (e.g., participants in the multi-player condition were unaware that there was a single-player condition). During each wave, the two sites trialed opposing conditions; when participants in the first site were in the multi-player condition, participants in the second site were in the single-player condition, and vice versa.

Several factors made randomization impractical for the trial. The trial was held at two sites; standardizing equipment for the trial meant that equipment was procured for each home (e.g., existing computers or exercise bicycles in the homes were not used); and online supervision by game monitors was necessary to troubleshoot hardware and software issues during game sessions. Double the amount of equipment and number of game monitors would have been required to randomize participants to different conditions at each location. Running a nonrandomized control trial made it possible to compare similarly sized groups and ensure that each site would trial both multi-player and single-player conditions.

Open session exergaming took place 5 days per week for 90 min in the early evening with online monitor supervision of the Liberi cycling game system. Weekly bike use was objectively recorded via system log-in and play duration. Total physical activity, including activity performed outside the game, was recorded via self-report. The study was granted ethical approval from the University of Victoria Human Research Ethics Board and Queen's University Health Sciences and Affiliated Teaching Hospitals Research Ethics Board. Prior to study commencement, the trial was registered at www.clinicaltrials.gov (identifier NCT02032667).

Intervention

Liberi

Liberi is a validated exergame originally developed using a participatory and iterative design approach to provide a moderate-to-vigorous intensity exercise stimulus for children with cerebral palsy [5, 38, 44]. It is a networked, cycling-based game that allows players to meet up, play together, and communicate with one another. Liberi contains a central plaza (island) that gives access to six different mini-games. The games are balanced to support differing player abilities and to support a variety of play styles. To promote long-term adherence, the central plaza also contains shops where players can purchase costumes for their avatars and upgrade their weapons using coins collected by playing the games. Originally, the games were only capable of being played with real players, but for this study, artificial intelligence opponents were developed to allow for solitary play.

Liberi consists of six mini-games; two are displayed in Fig. 1A, Gekku Race and Dozo Quest. Players compete against each other or against artificial intelligence opponents in the racing game, Gekku Race. In Dozo Quest, the goal is to traverse a maze and defeat or avoid opponents along the way, ultimately facing a boss at the end of the maze. Other games include Biri Brawl, which pits players against each other or against artificial intelligence opponents in a fast-pace fighting game. In Wiskin Defence, players attempt to defend Wiskins (rabbit-like creatures) while defeating wave after wave of increasingly tougher enemies. In Bobo Ranch, players lasso floating sheep with the goal of pulling the sheep into a barn. Finally, Pogi Pong is a space hockey game, in which players attempt to knock a star past the opponent's goal.

Equipment

As shown in Fig. 1B, participants played games using a Microsoft Surface Pro 2 tablet that was attached to a Vision Fitness R10 recumbent bike. To play games, participants had to pedal the bike. A YEI Bluetooth Sensor was attached to one of the pedals of the bike and sent gyroscopic data to the games in order to make in-game characters move. To control the direction of characters and perform in-game actions, participants used a Logitech F710 wireless gamepad. In order to talk to other players and hear in-game audio, participants wore a Logitech wireless headset while playing. Participants also wore a Garmin Soft Strap Premium Heart Rate Monitor, which sent heart rate data to the games.

Experimental conditions

The experiment consisted of two conditions, a multi-player condition, and a single-player condition. In the multi-player condition, participants played against or cooperated with each other. Players in the multi-player condition were connected by a network from home, could see other player's avatars in the game, and could speak to one another using headsets. In the single-player condition, participants only played against or cooperated with artificial intelligence opponents. For each participant's play session, the game kept a log of play that included the current time and date, the mini-game being played by the participant, how many total players were in the mini-game being played by the participant, the participant's cadence, and the participant's heart rate.

Monitoring

During each 90-min play session, game monitors were available to troubleshoot any issues that players had with hardware or software, to log significant gameplay events (e.g., which players were playing what games), and to ensure children were not acting or speaking to one another in an inappropriate manner. Game monitors could be phoned by the participants or contacted through text messages on Skype. Monitors were provided with software that allowed them to view the activity and avatars of any participant currently logged into the game and provided them with commands to aid in troubleshooting the game. Game monitors were not permitted to play the games with the children.

Procedure

Prior to study commencement, parental consent and child assent were obtained. Participants completed the Physical Activity Readiness Questionnaire for Everyone (PAR-Q+) to screen for pre-existing health conditions that might be exacerbated with exercise [45]. Once deemed eligible to participate, an orientation session was held at the participant's home, which included the delivery of a recumbent bike, tablet, game controller, headset, and the Liberi game. The parent or guardian then completed a demographics questionnaire. The parent or guardian assisted the child in completing the Physical Activity Questionnaire for Children (PAQ-C) [46, 47].

Participants played the game for 6 weeks. Two games were initially available to play during the first week of the trial. To foster motivation, a new game was released on Weeks 2, 3, 4, and 5. By the 6th week, there were six mini-games available to play. The order and timing of which games were offered was standardized across study conditions and locations. In both conditions, the games were open for an hour and a half block of time each weekday, scheduled at a time that was agreed upon by all families during orientation. Channeling players to a fixed block of time allowed the game to be easily overseen by game monitors and increased the chance of finding other people to play within the multi-player condition. No specific exercise prescription was assigned, but the participant was told to play the game as frequently as they could. The parent or guardian was informed about how the recumbent bike works, how to contact game monitors for troubleshooting, and when games would be available, but they were not told to encourage the child to play.

Primary Outcome Measures

Mean play session duration

Each participant's mean play session duration was calculated by dividing the total minutes the participant played in a week (play duration) by the number of days the player played that week (play frequency). The methods in which play duration and play frequency were measured are discussed in the next two sections.

Play duration

Play session logs were used to calculate play duration. The logs recorded every second of play, measured objectively using a sensor that determined whether a player was pedaling the recumbent bike. Weekly play duration was determined by accumulating the number of seconds of play recorded by the logs. Any interruption in play, such as if a child had played, stopped playing, and played again within the same session, was not accumulated in the calculation of play duration because the cadence sensor was not active during this interruption.

Play frequency

Participants were considered to have played on any day in which they logged into the game and performed any amount of pedaling. The number of days a participant played each week were summed to determine a participant's play frequency for that week of the study.

Secondary Outcome Measures

Play intensity

Participants wore a Garmin Soft Strap Heart Rate Monitor during gameplay. For each second of gameplay, play session logs recorded the participant's heart rate.

Heart rate was converted to MVPA minutes using methodology suggested by the American College of Sports Medicine (ACSM) [48]. While there are other methods to calculate MVPA, research has shown that maximal heart rate is stable throughout childhood and adolescence at approximately 200 beats per minute (bpm) [49, 50]. Therefore, a single cut-off value of 200 bpm for maximum heart rate was used for calculating MVPA for all participants, and minutes above 128 bpm (64% of maximum heart rate) are reported, which corresponds to the lower bound for moderate physical activity according to the ACSM.

When the heart rate monitor was not working properly, heart rate was simulated during gameplay. Simulated heart rate data were not included in the analysis. However, removing the data completely would result in underreported MVPA minutes. Instead, it was assumed that the distribution of participants' heart rate data would remain consistent throughout the trial. Thus, in the Results section, mean minutes above 128 bpm is scaled by a factor of total minutes played divided by valid heart rate minutes played, where total minutes played is the minutes played by all participants during the trial. Valid heart rate minutes played was calculated by removing minutes of gameplay in which heart rate was simulated from the total minutes played. Similar to Jago et al.'s study, valid heart rate data also excluded heart rate values <50 bpm or >210 bpm [51].

Total physical activity

Total physical activity was measured using the PAQ-C and collected at baseline and at 6 weeks. The PAQ-C is a validated, self-reported, 7-day recall physical activity measure, consisting of nine items that are used to calculate summary activity scores [46, 47]. Each PAQ-C item is scored on a five-point Likert scale, in which higher scores indicate higher levels of physical activity. Measures derived from this instrument have been found to demonstrate acceptable reliability as well as convergent validity in relation to objective measures of physical activity.

Exploratory Outcome Measure

Inactive play duration

There is an assumption that when players are in games, they are being physically active because the games require participants to pedal the bike to play. But, Liberi contains a large environment connecting the games, where players can socialize and shop. This grants them the opportunity to be idle, since socializing and shopping do not require players to pedal. We defined the duration players were in Liberi but not pedaling as inactive play duration, a variable we examined to ensure players were not spending large amounts of time inactive.

Sample Size Determination

G*Power 3 was used to conduct a priori power analysis to determine the total sample size necessary for the study. The analysis was based on our primary research question regarding play duration. Power analysis for a repeated measures ANOVA showed a sample size of 50 children (25 per group) would be required to detect a medium effect size (f^2 = .15) with a type one error of .05, a mean correlation of .75 across time, and 80% power [52, 53]. Our sample size considered the main 2 (group) x 6 (time) repeated measures design with a potential 15% attrition rate.

Statistical Analyses

Statistical analyses were performed using SPSS version 24.0 [54]. All statistical tests were two-tailed and maintained a 5% confidence level. Repeated measures ANOVA using a six-level within-subjects factor of week and a between-subjects factor of condition were performed on play duration, play frequency, and inactive play duration. A paired sample *t*-test was performed on inactive play duration. Welch's unequal variances *t*-test was performed on mean play session duration and intensity. Repeated measures ANOVA using a two-level within-subjects factor (pre-test, post-test) was performed on total physical activity.

Results

Participant Flow

Ninety-seven children were assessed for study eligibility. Twenty-five children were deemed ineligible due to not meeting the study's inclusion criteria (see Supplementary material 1). Seventy-two participants were deemed eligible. At Site 1, 40 participants were eligible: 16 were assigned to the single-player condition, and 24 were assigned to the multi-player condition. At Site 2, 32 children were eligible: 16 were assigned to the single-player condition, and 16 were assigned to the multi-player condition. Two participants were lost to drop-out. One was due to the participant becoming frustrated that study equipment did not work. The other was due to unhappiness on the family's part with the need to modify home networking infrastructure to accommodate the intervention. This was deemed a serious adverse event related to the study intervention. These participants were not included in analyses. A second adverse event occurred in which a participant complained that inappropriate language was used by another participant. This adverse event was resolved, and this participant's data were included in analyses. A total of 70 participants were included in the analyses.

Table 1 Baseline demographic profile

Characteristics	Single player (n = 32)	Multiple players (n = 40)	p-Value	Effect size (η_p^2)
Child profile				
Mean age (year) (*SD*)	10.16 (.88)	10.38 (1.05)	.34	.01
% Female (*SD*)	28.13 (45.68)	45.00 (50.38)	.14	.03
Mean BMI (*SD*)	20.49 (4.15)	20.85 (5.08)	.74	<.01
% Regular video game players (*SD*)	83.33 (37.90)	79.49 (40.91)	.69	<.01
Physical activity (PAQ-C) mean (*SD*)	1.35 (.14)	1.36 (.29)	.77	<.01
Video games (min/day) (*SD*)	78.60 (96.07)	68.17 (51.23)	.61	<.01
Computer games (min/day) (*SD*)	55.86 (45.35)	61.11 (36.49)	.66	<.01
Tablet/phone games (min/day) (*SD*)	52.78 (46.97)	52.19 (29.32)	.95	<.01
Total game usage (min/day) (*SD*)	193.20 (188.04)	181.47 (84.41)	.82	<.01

p-Values were calculated using independent samples t-tests.

Baseline Characteristics of Participants

Baseline characteristics of the participants can be found in Table 1. There were no significant differences among the groups on demographic or health-related variables, supporting the nonrandomization procedure. Children had a mean age of 10 years, about two-thirds were male, and about four-fifths were regular video game players who played video games for ~1.15 hr per day.

Primary Outcomes

Play session duration

As shown in Fig. 2A, mean play session duration was 37.65 (*SD* = 15.39) min/day. Mean play session duration was M = 40.97 (*SD* = 15.50) min/day in Week 1 and M = 35.57 (*SD* = 13.55) min/day in Week 6; the decrease across time was significant: $t(135) = 2.20, p = .03, \eta_p^2 = .03$. There was not a significant difference in mean play session duration in the multi-player (M = 38.64 min/day, *SD* = 16.68 min/day) and single-player (M = 36.46 min/day, *SD* = 13.48 min/day) conditions: $t(67) = .60, p = .55, \eta_p^2 < .01$.

Play duration

A participant could play for a maximum of 450 min per week. Displayed in Fig. 2B, mean play duration for participants was 133.45 (*SD* = 81.27) min in Week 1. In Week 6, mean play duration was still 77.23 (*SD* = 84.09) min. Mauchly's test indicated that the assumption of sphericity had been violated ($\chi^2(14) = 35.14, p < .01$). Degrees of freedom were corrected using Huynh–Feldt estimates of sphericity ($\varepsilon = .90$). Mean weekly play duration declined significantly across time [$F(4.52, 307.4) = 9.61, p < .01, \eta_p^2 = .12$]. There was no significant difference between conditions [$F(4.52, 307.4) = .75, p = .57, \eta_p^2 = .01$].

Play frequency

A participant could play for a maximum of 5 days per week. Mean play frequency was 3.27 days in Week 1 and 2.20 days in Week 6. Mauchly's test indicated that the assumption of sphericity had been violated ($\chi^2(14) = 31.06, p < .01$). Degrees of freedom were corrected using Huynh–Feldt estimates of sphericity ($\varepsilon = .92$). Mean weekly play frequency declined significantly across time [$F(4.58, 311.7) = 7.83, p < .01, \eta_p^2 = .10$]. There was no significant difference in frequency between conditions [$F(4.58, 311.7) = .15, p = .97, \eta_p^2 < .01$].

Secondary Outcomes

Play intensity

Heart rate was simulated (e.g., due to a non-working heart rate monitor) for 8.82% of the total duration played. Overall mean heart rate was M = 117.46 (*SD* = 10.90) bpm. There was not a significant difference in mean heart rate in the multi-player (M = 111.31 bpm, *SD* = 10.29 bpm) and single-player (M = 106.36 bpm, *SD* = 11.66 bpm) conditions: $t(58) = 1.85, p = .07, \eta_p^2 = .05$. Mean heart rate was M = 122.67 (*SD* = 10.84) bpm in Week 1 and M = 111.93 (*SD* = 8.00) bpm in Week 6. The decrease in mean heart rate was significant across time: $t(126) = 6.67, p < .01, \eta_p^2 = .24$. Players spent a mean of M = 27.97 (*SD* = 39.30) min/week in the moderate-to-vigorous intensity range. There was not a significant difference in mean minutes per week spent in the moderate-to-vigorous intensity range in the multi-player (M = 27.46 min/week, *SD* = 43.51 min/week) and single-player (M = 28.67 min/week, *SD* = 32.85 min/week) conditions: $t(67) = .13, p = .89, \eta_p^2 < .01$. Mean MVPA min was M = 49.15 (*SD* = 48.62) min in Week 1 and M = 11.08 (*SD* = 25.85) min in Week 6. The

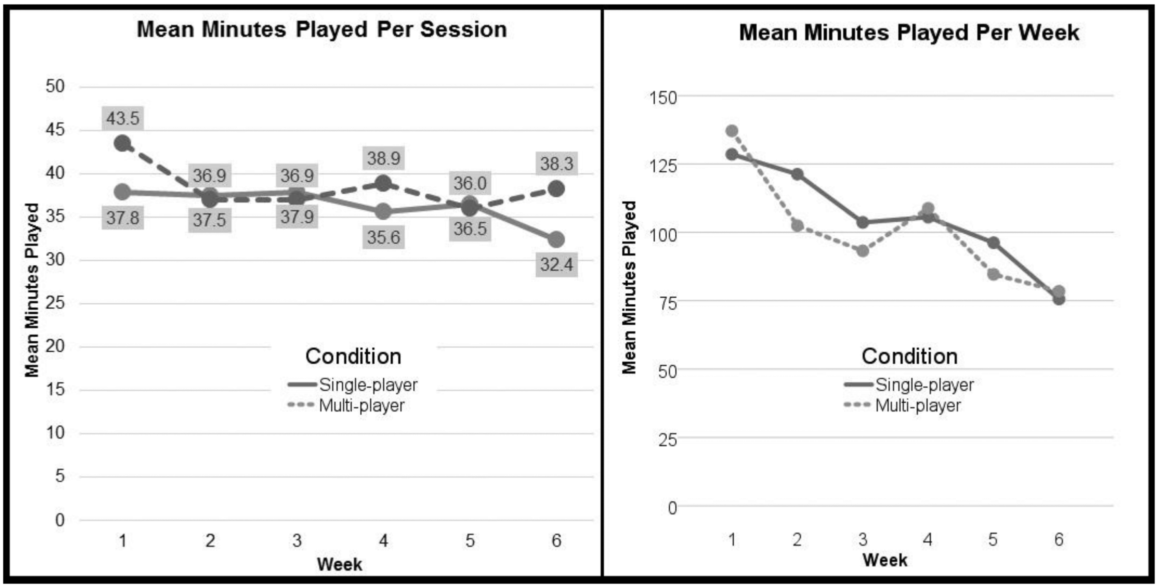

Fig. 2 (A) Weekly mean play session duration (min) for multi-player and single-player conditions. (B) Weekly mean play duration (min) for multi-player and single-player conditions.

drop in MVPA min was significant across time: $t(105) = 5.79$, $p < .01$, $\eta_p^2 = .20$. Players spent a mean of $M = 10.26$ ($SD = 14.42$) min/day in the moderate-to-vigorous intensity range. There was not a significant difference in mean MVPA minutes per day in the multi-player ($M = 14.42$ min/day, $SD = 10.53$ min/day) and single-player ($M = 10.26$ min/day, $SD = 9.94$ min/day) conditions: $t(67) = .17$, $p = .86$, $\eta_p^2 < .01$.

Total physical activity

Total physical activity was significantly higher at 6 weeks ($M = 2.63$, $SD = 0.69$) compared to baseline ($M = 2.37$, $SD = .61$) [$F(1, 52) = 7.44$, $p = .01$, $\eta_p^2 = .13$]. Total physical activity was not significantly different between conditions [$F(1, 52) < .01$, $p = .96$, $\eta_p^2 < .01$]. At baseline, total physical activity for participants in the multi-player condition was a mean of $M = 2.38$ ($SD = 0.68$), and the mean in the single-player condition was $M = 2.36$ ($SD = .49$). At 6 weeks, the total physical activity for participants in the multi-player condition was $M = 2.64$ ($SD = 0.73$), and the mean in the single-player condition was $M = 2.62$ ($SD = 0.65$).

Exploratory Outcome

Inactive play duration

Inactive play duration was $M = 20.4\%$ of total play duration. Mauchly's test indicated that the assumption of sphericity had been violated ($\chi^2(14) = 90.86$, $p < .01$). Degrees of freedom were corrected using Greenhouse–Geisser estimates of sphericity ($\varepsilon = .63$). Mean weekly inactive play duration declined significantly across time [$F(3.17, 215.39) = 8.61$, $p < .01$, $\eta_p^2 = .11$]. There was no significant difference in inactive play duration between conditions [$F(3.17, 215.39) = .77$, $p = .52$, $\eta_p^2 = .01$]. A paired sample *t*-test revealed that there was a significant mean difference between Week 1 and Week 6: $t(69) = 5.86$, $p < .01$, $\eta_p^2 = .33$. On average, Week 1 inactive play duration was 19.05 min longer than Week 6 (95% *CI* [12.57 min, 25.54 min]). Note that inactive play duration is included in the calculations for mean play session duration and overall play duration.

Discussion

Overall game usage

The World Health Organization and other agencies suggest that children participate in MVPA for 60 min daily [42]. However, marked health benefits can be accrued at much lower volumes and intensities of physical activity [11]. Maddison et al. suggested that if children played exergames for at least 30 min per day, it could have a demonstrable effect on body weight [24]. Exergames have been critiqued for short play session durations, in the range of 5–10 min, and past interventions have lent credence to this complaint [20, 21]. Past studies have generally used self-reported data for examining play duration, which can be substantively inaccurate.

A major strength of our trial is that it demonstrated that exergames can lead to high adherence levels, and it did so using data collected objectively through logs of play sessions. In both conditions, children were sufficiently engaged to play for a mean session duration exceeding 35 min. Fig. 2A shows that mean play session duration for both conditions was promising, as it was much longer than that reported in previous studies

[20, 21, 23, 24]. Consistent with prior research and our hypothesis, play intensity was in the light-to-moderate range [10]. Play duration decreased significantly across time for both conditions; this represented a medium effect size and was also consistent with our hypothesis. Promisingly, play duration remained high throughout the trial. The drop in total play duration across time was due to a significant reduction in play frequency (days played per week), representing a medium effect. Play frequency could have diminished due to technical issues or life changes, such as participation in extracurricular activities. There are other activities that are beneficial to physical fitness, such as sports, and exergaming is just one part of a larger physical activity palette. Choice of activities should be autonomous, and future research should focus on improving frequency of play among children who enjoy exergames.

Multi-player versus single-player game usage

We hypothesized that participants in the multi-player condition would play longer overall. However, multi-player capabilities did not augment adherence levels, as there was no significant difference in play duration between conditions; this was a small effect size. We speculate that there are two possibilities, one or both of which may have contributed to not seeing a significant difference between conditions.

First, we were consistently releasing a new stream of games throughout the trial. It is possible that incorporating new games as the study progressed was sufficiently motivating to keep both groups playing, regardless of whether that was play against artificial intelligence opponents or real players, but this should be formally tested in future trials. Previous research has found that a single game may become unappealing, while Graves et al. found that incorporating multiple games in a trial may minimize the effect of over-familiarization [21–23].

A second possibility involves how we implemented multiplayer capabilities. The success of multiplayer play is usually due to the establishment of social groups with the other players. We provided headsets and included voice chat so that players could hear and talk to each other in the game. Players could also see each other's avatars (e.g., the digital representation of a player) and play games with one another. However, none of the participants had met before the trial. It is possible that some people found it difficult to establish a social group with strangers, and the impersonal forms of communication we provided could have contributed to a lack of group cohesion. Future studies may benefit from pre-trial sessions so that participants become familiar with one another in person. Trials may also benefit from encouraging participants to socialize with the other participants outside of the exergame.

Play intensity

Consistent with prior research and our hypothesis, play intensity was in the light-to-moderate range [10], which can lead to marked health benefits [11]. While there was no significant difference between conditions, overall mean heart rate decreased significantly over time, with a large effect size. This decline in heart rate may be due to the algorithm used to balance pedaling ability among players. Specifically, we used a one-speed-for-all algorithm that gave all players the same speed, no matter how hard they pedaled. As the players became familiar with the games over time, they may have realized that they did not have to pedal hard to go full speed in the games. Balancing for differing physical abilities is important so that all players enjoy the games, regardless of differences in physical fitness, but future studies may benefit from a different balancing algorithm than the one-speed-for-all algorithm we used.

Even so, the significant decline in heart rate was surprising because we implemented game features to incent participants to play at a moderate intensity range. In particular, Liberi includes heart-rate power-ups, which grant players greater abilities in the games when they reach a target heart rate level, such as enabling the use of a weapon to slowdown opponents in the Gekku Race game [55]. Given our prior success with incenting moderate-to-vigorous intensity levels using heart-rate power-ups, we believed the same results would be achieved in this study [55]. Unfortunately, this was not the case, and further study is warranted to discover whether heart-rate power-ups are effective at augmenting heart rate levels in longer-term trials.

Cooperative and competitive gameplay may produce different exercise intensities. The Liberi game was played in separate spaces and included both cooperative and competitive games. Current research in competitive versus cooperative exergame play have produced mixed results. For instance, Peng and Crouse found parallel competition with another player in a separated physical space led to higher enjoyment, future play motivation, and intensity levels when compared to a cooperative exergame in the same physical space [56]. On the other hand, Staiano et al. found that cooperative exergame play led to significantly more weight loss compared to a control group, whereas the competitive exergame players did not differ significantly from either the cooperative or control group [57].

Total physical activity

There has been some concern that exergames may displace time that could be used for other physical activities and authentic sports, which may elicit better physical benefits than exergaming alone [20]. However, total physical activity was significantly higher at 6 weeks compared to baseline in a moderate-to-large effect size range. This effect size supports the contention that the exergames may in fact *augment* physical activity, but it should be noted that this was self-reported data, and thus, may not be accurate.

Inactive play duration

In Liberi, it can be assumed that players are actively pedaling when they are in games since games require pedaling to play. But games are connected by a large island that contains shops and grants players the ability to be idle, whether that is to peruse shops for upgrades or even to socialize. In planning the study, we identified the possibility that players might spend a large amount of their time being stationary, not pedaling, when they were on the island. We explored inactive play duration to determine if this was the case. Instead, we found that players were *actively engaged* with Liberi most of the time they were playing. Encouragingly, players were also becoming more active as the study progressed, as the decline in inactive play duration was significant across time, and this was a medium effect size.

Conclusion

We conducted five waves of 6-week trials at two sites in Canada across two conditions, comparing a single-player to a multi-player exergame condition. Promisingly, mean session play duration was much higher than in previous studies [20, 21, 23, 24], which demonstrated that the games sufficiently motivated the players to keep playing them once they started playing. Overall play duration was also quite high throughout the study. It had been hypothesized that the social aspects of multi-player gameplay would elicit greater overall play than the single-player condition. However, we found that multi-player features did not augment the already high play duration. The decrease across time was due to a drop in frequency of play. For children who enjoy exergames, future studies should focus on getting players to play more days per week.

Limitations of our study that prevent generalizability include the 6-week trial duration and the use of self-reported total physical activity data. Due to a lack of randomization, differences between the groups that were present before the intervention may have also affected the study's outcomes. The choice of games and exercise equipment used in exergaming studies may affect adherence and intensity levels. Some researchers have used off-the-shelf console exergames, some have converted off-the-shelf console games into exergames, and others have developed custom exergames. The type of social play afforded by the exergames selected for study may also affect adherence behaviors. Both cooperative and competitive games were available to play in our study, which may produce conflicting intensities [56, 57]. As it stands, our study adds to the literature of multi-player exergaming by using objective measures, but social play in exergaming remains a rich avenue for future research.

Supplementary Material

Supplementary material is available at *Annals of Behavioral Medicine* online.

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Authors' Contributions All authors contributed to the study design. RER undertook sample size calculations, and MDK, NG, and RER designed the statistical analysis plan. In addition to the study design, NG was the primary investigator for the Kingston team, and RER was the primary investigator for the Victoria team. MDK contributed to the set-up and take-down of equipment, designed software for detecting and communicating pedaling motion from the exercise bike to the games, and assisted with running the trial. MDK assisted with troubleshooting hardware and software issues and monitoring game use during the trial. MDK developed the process for organizing and analyzing data collected during the trial, and performed statistical analyses of the data. SB and HH assisted with setting up and running the trial, including hiring and training game monitors and conducting pre- and post-trial interviews. CY assisted with running the trial and aided in statistical analyses. ZY developed the Liberi game, troubleshot software issues with the games, and integrated the software developed by MDK in the game. MDK, MB, ALC, DERW, NG, and RER contributed to reporting the findings in this manuscript.

Ethical Approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. The study was granted ethical approval from the University of Victoria Human Research Ethics Board and Queen's University Health Sciences and Affiliated Teaching Hospitals Research Ethics Board.

Informed Consent Informed consent was obtained from all individual participants included in the study.Compliance with Ethical Standards

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