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ORIGINAL ARTICLE

Active video gaming in primary ciliary dyskinesia: a randomized controlled trial

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Abstract

Primary ciliary dyskinesia (PCD) impairs pulmonary function, respiratory and peripheral muscle strength, and exercise capacity. We aimed to investigate the effects of active video games (AVGs) on pulmonary function, respiratory and peripheral muscle strength, exercise capacity, muscle oxygenation (SMO_2), physical activity, activities of daily living (ADL), and quality of life (QOL) in PCD. Thirty-two PCD patients were randomly assigned to AVG group ($n=16$) and the control group ($n=16$). AVG group underwent AVGs using Xbox-Kinect-360 device for 40 min/day, 3 days/week for 8 weeks plus airway clearance techniques (ACT), and the control group was applied ACT only. Pulmonary function, respiratory and quadriceps muscle strength, exercise capacity (6-min walk test [6MWT], incremental shuttle walk test [ISWT]), and ADL (Glittre ADL test) were assessed. SMO_2 during ISWT and ADL test was also recorded. Physical activity and QOL (PCD-QOL) were evaluated. Pulmonary function; respiratory and quadriceps muscle strength; 6MWT and ISWT distance; physical activity; ADL performance; SMO_2; physical, emotional, and social functioning; treatment burden; and upper and lower symptom parameters of PCD-QOL significantly improved after 8 weeks in the AVG group ($p<0.05$). There were no significant differences in measured parameters except emotional function and upper respiratory symptom scores of PCD-QOL in the control group ($p>0.05$).

Conclusion: The AVGs positively affect pulmonary (pulmonary function, respiratory muscle strength) and extrapulmonary (peripheral muscle strength, exercise capacity, SMO_2, physical activity, ADL, and QOL) characteristics in children with PCD. The AVGs may be added to the pulmonary rehabilitation program as an exercise training modality in patients with PCD.

Trial registration: This study registered at ClinicalTrials.gov with NCT03832491 on February 6, 2019.

What is Known:
- *It is indicated that exercise capacity isincreased with traditional exercise-training in a case report of KartagenerSyndrome.*

What is New:
- *No randomized controlled studyinvestigated the effects of exercise-training in PCD.*
- *8-week moderate-intensity active video gaming(AVGs) improves pulmonary and extrapulmonary features in children with PCD.AVGs may be preferable due to being enjoyable, providing visual and audialfeedback in the pulmonary rehabilitation programs of PCD.*

Keywords Primary ciliary dyskinesia · Muscle strength · Active video gaming · Exercise capacity · Activities of daily living · Physical activity

Abbreviations

ACT	Airway clearance techniques
ADL	Activities of daily living
AVGs	Active video gaming
CF	Cystic fibrosis
FEV_1	Forced expiratory volume in one second
$FEF_{25-75\%}$	Forced expiratory volume 25–75%
FVC	Forced vital capacity
ISWT	Incremental shuttle walk test
MEP	Maximal expiratory pressure
MIP	Maximal inspiratory pressure
PAL	Physical activity level
PCD	Primary ciliary dyskinesia
PEF	Peak expiratory flow rate

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PF	Pulmonary function
SMO_2	Muscle oxygenation
QOL	Quality of life
6MWT	Six-minute walk test

Introduction

Primary ciliary dyskinesia (PCD) is a rare, heterogeneous, genetic disease characterized by congenital defects and motile cilia dysfunction [1]. Chronic respiratory tract infection, chronic productive cough, heterotaxia, and otitis media are clinical manifestations of PCD [1, 2]. There is no clarity about the medical treatment in PCD and the therapeutic strategies of cystic fibrosis (CF) are used in management in PCD even if the pathology of CF and PCD is different [1, 2]. Airway clearance techniques (ACT) are used to facilitate mucus clearance in PCD [2].

Health status and barriers to participation in exercise might affect activities of daily living (ADL) in children with chronic lung diseases (CLD) [3]. Physical fitness, physical activity level (PAL), and ADL are associated with quality of life (QOL) in CF [4, 5]. Similar to CF, PCD patients have decreased pulmonary function (PF), quadriceps strength, respiratory muscle strength, exercise capacity, ADL, and QOL [3, 6–8].

Physical inactivity is one of the most critical problems in children with CLD. Children participate in traditional exercise training less than adults because of finding it boring [9, 10]. Lately, interactive and virtual reality systems, including active video gaming (AVGs), have made repetitive exercise enjoyable [9–12]. AVGs positively affect exercise capacity and peripheral muscle strength in children with CLD [9, 10, 12]. The greater enjoyment when using AVGs with lower dyspnea and fatigue perception than stationary bicycle training was reported [9]. Compared with traditional management, home-based AVGs improved muscle strength, exercise capacity, and QOL in CF [10]. In asthma, both AVGs and treadmill training increased exercise capacity; however, maximum energy expenditure (EE) was higher in the AVG group [12].

The effectiveness of exercise training in PCD is uncertain [2]. Improvement in peak expiratory flow (PEF) with exercise and effect of exercise on bronchodilation are greater than β2 agonist therapy in PCD [13]. A case report stated that exercise capacity increased after 8-week aerobic exercise training in addition to ACT in a patient with Kartagener's syndrome, which is a type of PCD [14]. The AVGs may be helpful to improve PF, muscle strength, exercise capacity, PAL, ADL, and QOL in PCD. Therefore, this study was planned to investigate the effects of AVGs on PF, respiratory and peripheral muscle strength, exercise capacity, muscle tissue oxygenation (SMO_2) during exercise, PAL, ADL, and QOL in PCD. We hypothesized that AVG training positively affects pulmonary and extrapulmonary features in PCD.

Materials and methods

This study was a prospective, randomized controlled trial approved by Hacettepe University Clinical Research Ethics Committee (03/09/2018, KA180026), registered at ClinicalTrials.gov (NCT03832491) and conducted between May 2019 and February 2020 at Hacettepe University, Faculty of Physical Therapy and Rehabilitation. Written informed consent was obtained from all patients and their families.

Participants and randomization

The primary outcome was 6-min walk test (6MWT) distance. When the effect size (d) is accepted as 1.01, to determine the difference between the groups with 90% power and 5% type 1 error, it was calculated that 16 subjects with 10% unresponsiveness rate should be included in each group of the study [12]. Participants were randomly assigned to two groups using a computer-based program (www.graphpad.com/quickcalcs) program: the AVG group ($n = 16$) and the control group ($n = 16$). Diagnosed with PCD according to the guideline [15], being 6–18 years old, clinically stable, and volunteer for the study were the inclusion criteria. According to the genetic test results, two of the participants had HYDIN, five of the participants had DNAH5, three of the participants had RSPH4, two of the participants had CCNO, one of the participants had DNAH1, one of the participants had CCDC40, and two of the participants had DNAH11 mutation. Other participants of the study had been diagnosed according to the lower nasal NO level, observed immobile or dysmotile cilia movements in the video microscopic analysis, and guideline transmission electron microscopy (TEM) analysis results in addition to clinical findings. Having an unstable condition, severe neurological, musculoskeletal, rheumatologic, cardiovascular diseases, and being unable to perform the tests were exclusion criteria.

Measurements

PF was evaluated using a spirometer (Spirobank II, Medical International Research, Rome, Italy) [16]. Forced expiratory volume in 1 s (FEV_1), forced vital capacity (FVC), FEV_1/FVC, PEF, and forced expiratory volume 25–75% ($FEF_{25-75\%}$) were recorded. Maximal inspiratory pressure (MIP) and maximal expiratory pressure (MEP)

were assessed using a mouth pressure device (Micro Medical MicroRPM, Rochester, England) [17]. Quadriceps strength was evaluated using a hand-held dynamometer (JTECH, Medical Commander Powertrack II, Salt Lake City, USA) [18]. The mean value of both extremities' muscle strength was used for analysis.

Functional capacity was assessed using 6MWT twice in the same day with an interval of half an hour, and the best 6MWT distance was recorded [19]. Maximal exercise capacity was evaluated using the incremental shuttle walk test (ISWT) [19]. ADL was assessed using Glittre ADL test, consisting of completing a lap five times as quickly as possible [4]. HR was measured using a pulse oximeter (PalmSAT 2500, Nonin Medical Inc., Plymouth, MN, USA) during 6MWT and Glittre ADL test, and using Polar HR monitor (Polar S610i; Polar Electro Oy, Kempele, Finland) during ISWT. Blood pressure, SpO_2 using a pulse oximeter (PalmSAT 2500, Nonin Medical Inc., Plymouth, MN, USA), perceived dyspnea, and fatigue using the Omnibus (OMNI) scale [20] were recorded before and after 6MWT, ISWT, and Glittre ADL test. The SMO_2 during ISWT and Glittre ADL test was evaluated using a wearable lactate threshold device (BSXinsight, BSX Athletics, Boston, USA) [21].

Bouchard Three-Day Physical Activity Record (BAR) was used to assess PAL [22]. The health-related QOL instrument for PCD (PCD-QOL Version-2) forms for children (6–12 years), adolescents (13–17 years), and adults (≥ 18 years) was used [23].

All measurements were performed face to face with children before and after 8 weeks. The assessor was blinded to the study groups.

Interventions

The AVG group underwent supervised AVGs at a moderate intensity (3–6 metabolic equivalent (MET)) using the Xbox-Kinect-360 device (Xbox Kinect, Microsoft, Redmond, WA, USA) for 40 min/day, 3 days/week for 8 weeks. Five games (tennis, skiing, volleyball, football, track and field) from Kinect Sports and Kinect Sports Season-Two compact discs were chosen according to real sports simulations that used both upper and lower extremities. Each game's exercise intensity was determined using SenseWear Armband (SWA) (Armband Model MF-SW, Body Media, Pittsburgh, USA) for each patient before AVG sessions. The AVG protocol was determined, including 5 min to warm-up at the lowest level at the beginning, 30 min of training at moderate intensity, and 5 min cooling-down seasons at the lowest level at the end of the game for each session [12].

Participants included both groups continued ACT program as usual care with their oscillatory device or active cycle of breathing techniques (ACBT) with manual techniques. The techniques were taught by a physiotherapist and recommended to be applied as a home-based therapy every day, for 30 min, and two times a day for 8 weeks. Participants of both groups were given ACT diaries and called every week to check whether they performed the treatment and filled out their ACT diary regularly.

Statistical analysis

Statistical analysis was performed using the Statistical Package for Social Sciences (SPSS) version 20.0 (IBM Corp., Armonk, NY, USA). The data were presented as mean ± SD, frequencies, percentages, and median (IQR). Data normality was evaluated using the Shapiro–Wilk test. Student *t*-test or Mann–Whitney *U*-test was used to compare the baseline variables, as appropriate. Categorical data were compared with the chi-square test. Within-group comparisons of change in assessed parameters after 8 weeks' program was analyzed using paired *t*-test or Wilcoxon test, as appropriate. Mann–Whitney *U*-test or Student *t*-test was used to compare the change in the measured parameters between two groups, as appropriate. Effect size was calculated and considered small (0.2), medium (0.5), large (0.8), and very large (1.3) [24]. The probability of error was set as $p < 0.05$.

Results

Forty-five PCD patients were screened for the eligibility of the study. Six of them were excluded due to not meeting the inclusion criteria, and three of them refused to participate in the study. Thirty-six PCD patients were initially volunteered; however, one patient from the intervention group and three patients from the control group did not continue to the program. Therefore, a total of 32 PCD completed the program and the data of 32 patients with PCD was analyzed (Fig. 1).

Baseline demographic and physical characteristics were similar in two groups (Table 1). In AVG, EE of tennis game was 3.71 ± 1.22 MET, skiing was 5.23 ± 1.37 MET, volleyball was 4.55 ± 1.10 MET, football was 3.68 ± 1.62 MET, and track and field was 4.33 ± 1.56 MET (Table 1).

There was no significant difference in baseline PF values between two groups. FEV_1 %, FVC %, FEV_1/FVC, and PEF % were significantly improved in the AVG group ($p < 0.05$, Table 2). There were no significant changes in FEV_1 %, FVC %, FEV_1/FVC, PEF %, and FEF_{25-75} % in controls ($p > 0.05$, Table 2). The changes in FEV1 %, FVC %, and PEF % were more remarkable in the AVG group as compared to the controls ($p < 0.05$, Table 2, Fig. 2).

Baseline respiratory and peripheral muscle strength, functional capacity, and exercise capacity were similar in groups. MIP, MEP, QMS, 6MWT distance (6MWD), and ISWT distance (ISWD) were increased in the AVG group after 8 weeks. The changes in MIP, MEP, QMS, 6MWD,

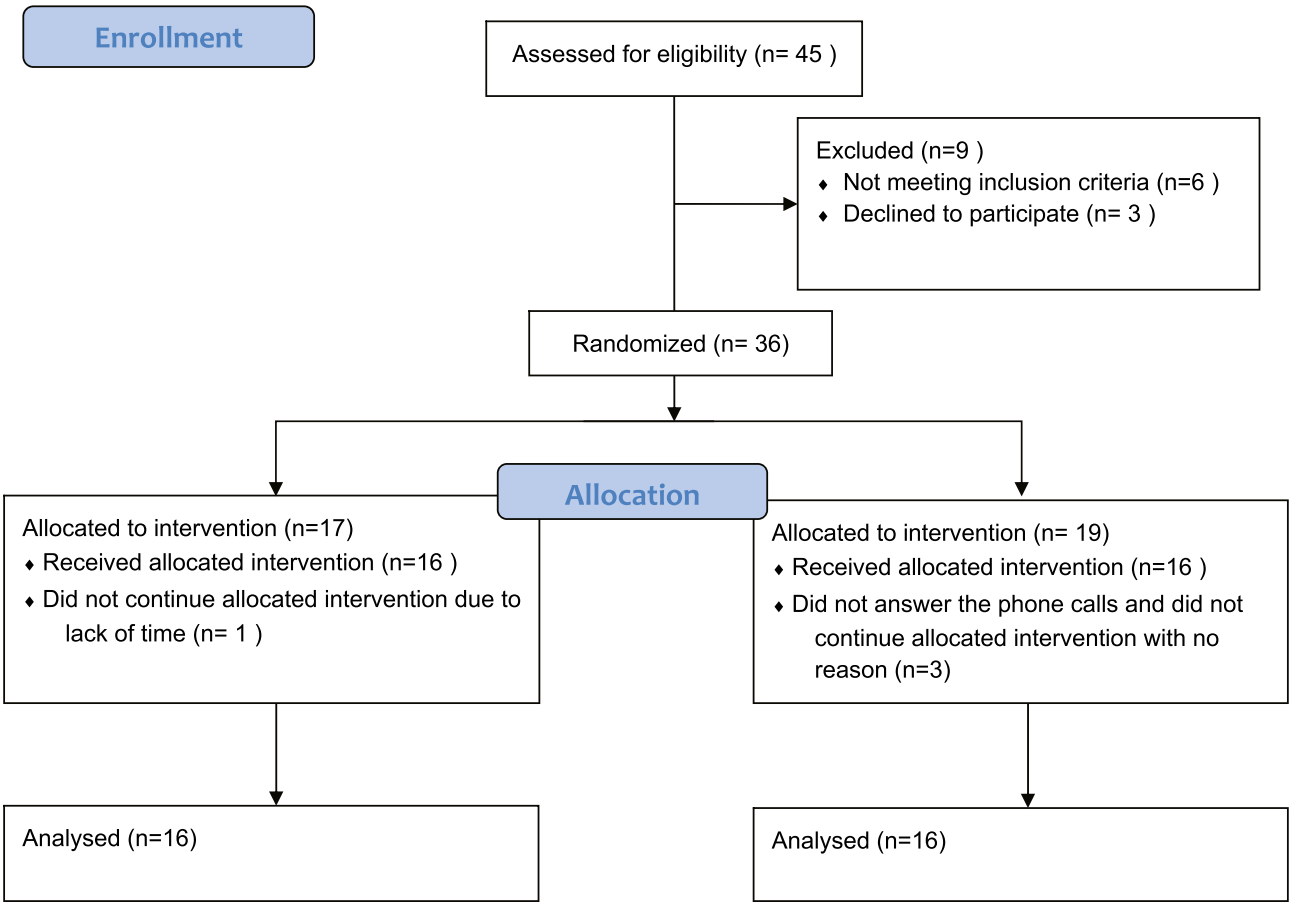

Fig. 1 Flow chart of the study

and ISWD were higher in the AVG group compared to controls after 8 weeks (Table 2, Fig. 3). There was no significant difference in baseline values of SMO_2, ADL level, and parameters of BAR and QOL between groups. The Glittre ADL test duration; SMO_2 change during ISWT and Glittre ADL test; PAL; physical, emotional, and social function; treatment burden; and upper and lower respiratory symptom scores of the PCD-QOL questionnaire were significantly improved with AVGs ($p < 0.05$, Table 2). However, there was no significant difference in ear and hearing symptom parameters of the PCD-QOL questionnaire in the AVG group ($p > 0.05$, Table 2). In the controls, Glittre ADL test duration, SMO_2 change during ISWT and Glittre ADL test; PAL; PCD-QOL questionnaire's physical, social functioning; treatment burden; lower respiratory symptoms; and hearing symptom score level did not differ significantly after the treatment ($p > 0.05$, Table 2). When two groups were compared, the changes in Glittre ADL test duration, SMO_2 during ISWT and Glittre ADL test, PAL, physical and social functioning, treatment burden, and lower respiratory symptom parameters of PCD-QOL were higher in the AVG group than the control group after 8 weeks ($p < 0.05$, Table 2).

Table 1 Baseline demographic and physical characteristics, and energy expenditure values of each game used in active video gaming and control groups

Variables	AVG group ($n=16$)	Control group ($n=16$)	p value
Age (years)	14.37 ± 2.75	12.99 ± 3.56	.229
Gender (female/male)	9/7	9/7	1.000
Weight z score	.10 (− 1.20 to 1.77)	− .10 (− 1.32 to 3.55)	.450
Height z score	.25 (− 1.48 to 1.58)	− .25 (− 1.87 to 1.32)	.355
BMI z score	− .03 (− 1.12 to 1.24)	.03 (− 0.82 to 4.23)	.792
Energy expenditure during each game assessed before active video gaming program in active video gaming group			
Tennis (MET)	3.71 ± 1.22		
Skiing (MET)	5.23 ± 1.37		
Volleyball (MET)	4.55 ± 1.10		
Football (MET)	3.68 ± 1.62		
Track and Field (MET)	4.33 ± 1.56		

Normally distributed variables were given as mean ± SD. Not normally distributed variables were given as median (IQ)

BMI body mass index, *MET* metabolic equivalent of task

Discussion

Our study showed that moderate-intensity 8-week AVGs increased exercise capacity. In additon, PF, respiratory and peripheral muscle strength, sMO_2, PAL, ADL, and QOL improved in the AVG group. PCD patients in the AVG group tolerated the AVG program well. Due to being enjoyable, PCD patients in the AVG group might enable to regularly participate in exercise training in our study.

PCD patients have reduced peak oxygen consumption due to decreased PF and PAL [6]. Peripheral muscle tissue oxygenation is associated with functional capacity in CLD [25]. Our results showed a 46.6 m and 48.12 m increase in the 6MWD and ISWD, respectively, with AVGs. Change in 6MWD in the AVG group is on the margin of minimal clinically important difference MCID [26]. The MCID of ISWD in healthy or children with CLD is unknown. Del Corral et al. stated that the mean change of modified ISWD was 62 m in the AVG group and the training protocol including upper and lower extremity movements assuring the high intensity exercise may be the reason for exercise capacity increase with AVGs in CF [10]. Additionally, cardiorespiratory fitness improves with exercise due to the structural and functional adaptations in the oxygen transport system [27]. The selected games used both upper and lower extremities for the present study's training protocol increased PF, SMO_2, and muscle strength in the AVG group. These increases may be explanatory for the increase in exercise capacity with AVGs in our study.

SMO_2 defines the balance between local oxygen supply in the muscle [28] and impairs in children with CF and non-CF bronchiectasis [29]. We found improved SMO_2 during ISWT and Glittre ADL test in the AVG group compared to the controls. There is a lack of study investigating the change in SMO_2 during exercise in children with CLD. One study showed that aerobic exercise training with stationary cycle improved SMO_2 due to increased cardiovascular function and muscle perfusion in children with congenital heart diseases [30]. In our study, improved peripheral SMO_2 in the AVG group might result from the enhanced peripheral muscle metabolism due to central and peripheral adaptations.

Peripheral muscle strength was found to be decreased in PCD [7, 31]. No study investigated the effects of aerobic exercise training on peripheral muscle strength in PCD. Previous findings revealed improved peripheral muscle strength after home-based AVGs in CF [10]. We observed significant improvement in quadriceps strength with AVGs. Decreased phosphocreatine recovery time is associated with improved oxidative capacity in PCD [31] and increased proportion of oxidative type I and hybrid muscle fibers with aerobic exercise training [32]. These mechanisms may be responsible for the increase in peripheral muscle strength in the AVG group in our study.

PF decreases in PCD [3, 6, 7]. It was thought that airway smooth muscle hypertrophy and fibrosis, secretions, and impaired pulmonary mechanics might be the possible mechanisms of the airflow limitation in PCD patients [13]. There is no randomized controlled study investigating the effects of exercise training on PF in patients with PCD. Gomes et al. compared the effects of AVGs and treadmill training in children with asthma and found the FEV_1 (%) and FEV_1/FVC (%) in the AVG group [12]. Salh et al. indicated that exercise might have a role in aiding mucus clearance in CF [33]. Kriemler et al. stated that values of the FEV_1 and FVC were increased after 3 months of supervised aerobic exercise program compared to baseline values in

Table 2 Changes in lung function, respiratory and peripheral muscle strength, muscle oxygenation, exercise capacity, physical activity, Glittre ADL test duration, and quality of life in active video gaming and control groups

Parameters	AVGs		Effect size	Intragroup difference *p*	Control		Effect size	Intragroup difference *p*	Intergroup *p*
	Baseline	Post			Baseline	Post			
Pulmonary function									
FEV_1 (%)	74.85 ± 9.76	81.77 ± 9.19	0.73	**0.001***	78.68 ± 12.14	77.82 ± 11.34	0.07	0.563	**0.001***
FVC (%)	84.5 (61 to 98)	92 (76 to 106)	0.76	**0.001***	85 (65 to 109)	85 (61 to 111)	0.01	0.345	**0.003***
FEV_1/FVC	73.6 (63 to 89.8)	77.5 (63.7 to 93.8)	0.54	**0.002***	76 (70.9 to 90.9)	78.4 (60 to 91.6)	0.19	0.276	0.122
PEF (%)	70.5(51 to 97)	78.5 (64 to 104)	0.56	**0.005***	72.5 (58 to 106)	72.5 (48 to 108)	0.28	0.608	**0.003***
$FEF_{25-75\%}$ (%)	53.5 (32 to 85.5)	50 (32 to 85)	0.14	0.083	60.5 (46 to 75)	60.5 (46 to 98)	0.16	0.180	0.171
Respiratory and peripheral muscle strength									
MIP (cmH_2O)	72 (58 to 104)	98.98 (63 to 125)	1.27	**< 0.001****	75 (53 to 114)	74.5 (55 to 116)	0.02	0.104	**< 0.001****
MEP (cmH_2O)	98.31 ± 19.38	110.56 ± 22.03	0.59	**0.012***	92.12 ± 17.42	92.62 ± 15.98	0.02	0.179	**< 0.001****
Quadriceps muscle strength (kg)	19.18 ± 5.69	26.39 ± 6.51	1.17	**< 0.001****	21.85 ± 7.99	23.78 ± 8.48	0.23	0.057	**0.006***
6MWT									
6MWD (m)	569 (428 to 683)	613.5 (452 to 737.6)	0.61	**< 0.001****	492 (425 to 619)	503 (407.6 to 644.3)	0.11	0.056	**< 0.001****
ISWT									
ISWD	705 (530 to 910)	735 (580 to 1020)	0.41	**< 0.001****	710 (500 to 870)	710 (520 to 880)	0.06	0.078	**< 0.001****
ISWD-ΔSMO_2 (%)	−0.56 ± 4.67	−8.68 ± 3.51	1.96	**< 0.001****	−0.56 ± 2.27	−1.56 ± 1.89	0.47	0.228	**< 0.001****
Glittre ADL test									
Glittre ADL test duration	234 (190 to 298)	144 (92 to 249)	2.71	**< 0.001****	211 (152 to 299)	220.5 (176 to 340)	0.07	0.897	**< 0.001****
Glittre ADL test-ΔSMO_2 (%)	−1 (−13 to −4)	−9 (−13 to 5)	2.17	**< 0.001****	−2 (−12 to 4.00)	−1 (−10 to 2)	0.31	0.192	**< 0.001****
Physical activity									
Mean kcal for 3 days (kcal/day)	1.48 (0.81 to 2.78)	1.99 (1.46 to 2.76)	1.03	**0.004***	1.43 (0.89 to 3.18)	1.34 (0.84 to 1.81)	0.48	0.605	**< 0.001****
QOL									
Physical function	39.68 ± 17.47	73.85 ± 18.33	1.90	**0.001***	40.50 ± 16.76	43.37 ± 14.94	0.18	0.068	**< 0.001****
Emotional function	44.89 ± 20.52	62.98 ± 21.00	0.87	**0.007***	43.57 ± 18.78	56.90 ± 22.09	0.65	**0.041***	0.573
Social function	44 (25 to 83.3)	66.6 (33.3 to 100)	0.91	**0.006***	45.8 (22.2 to 75)	46.5 (16.3 to 75)	0.19	0.790	**0.003***
Treatment burden	49.55 ± 19.38	64.64 ± 16.45	0.83	**0.001***	59.33 ± 16.23	59.23 ± 18.60	0.05	0.966	**< 0.001****
Upper respiratory symptoms	48.91 ± 14.89	65.70 ± 21.02	0.92	**0.001***	51.04 ± 13.03	57.60 ± 15.02	0.46	**0.005***	0.050
Lower respiratory symptoms	45.43 ± 13.32	60.01 ± 13.95	1.06	**< 0.001***	48.77 ± 12.49	51.53 ± 14.00	0.20	0.198	**< 0.001****
Hearing symptoms	70.8 (11.1 to 100)	68.3 (11.1 to 100)	0.07	0.752	60 (33.3 to 91.6)	60 (33.3 to 91.6)	0.09	0.575	0.819

Normal distributed variables were given as mean ± SD. Not normally distributed variables were given as median (IQ)

FEV_1 forced expiratory volume in 1 s, *FVC* forced vital capacity, *$FEF_{25-75\%}$* forced expiratory volume from 25 to 75%, *PEF* peak expiratory flow rate, *MIP* maximal inspiratory pressure, *MEP* maximal expiratory pressure, *6MWT*, 6-min walk test, *6MWD* 6-min walk test distance, *ISWT* incremental shuttle walk test, *ISWD* incremental shuttle walk test distance, *SMO_2* muscle oxygenation, *ADL* activities of daily living, *QOL* quality of life

*< 0.05; ** < 0.001

CF patients [34]. Exercise plus traditional physiotherapy plays the role in secretion clearance in CLD [35]. Gruber et al. showed that PF improves with regular exercise training in CF patients [36]. We found a significant increase in PF in the AVG group compared to the controls in consistent with the literature. Supervised aerobic exercise plus ACT were applied in the AVG group and this combined therapy might lead to decrease in airflow limitation as a result of the increase in the sputum clearance.

Increased airway resistance and gas trapping lead to impaired respiratory muscles' kinetics in CLD [37], and respiratory muscle strength is affected in PCD [3]. The effects

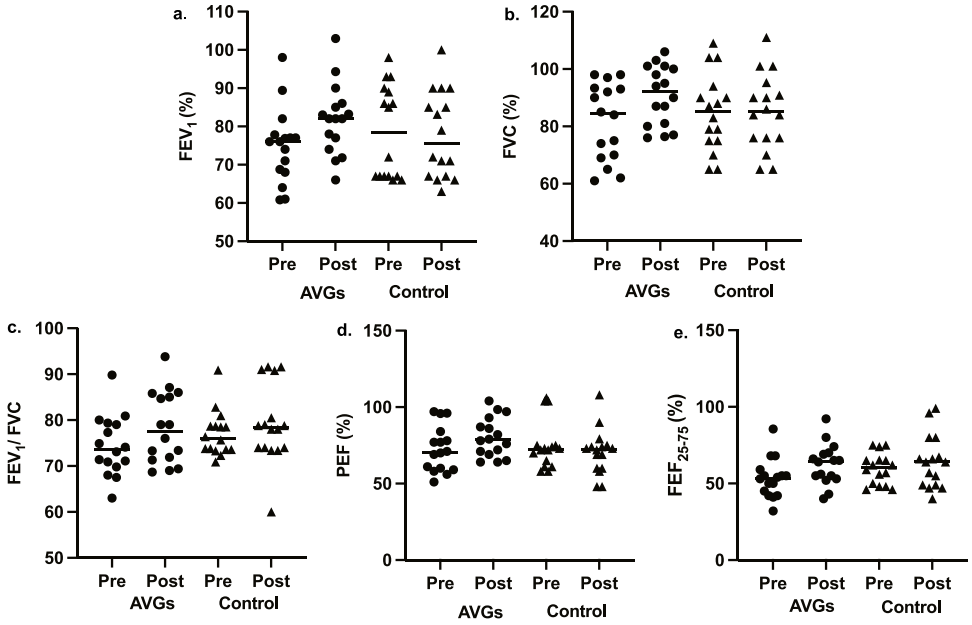

Fig. 2 Pulmonary function in active video gaming group and control group pre- and post-treatment program. Abbreviations: FEV_1, forced expiratory volume in one second; FVC, forced vital capacity; FEF_{25-75} %, forced expiratory volume from 25-75%; PEF, peak expiratory flow rate

of aerobic exercise training on respiratory muscle strength in PCD patients are unknown. Studies indicated that aerobic exercise training improves respiratory muscle strength in children with asthma due to adaptation to the physical effort with training [38]. Exercise training provides forceful inhalation and lungs' exhalation, increasing oxidative fibers and enzyme activity [39]. We found that respiratory muscle strength increased with AVGs. Forceful inflation and deflation of lungs and improved oxidative capacity with exercise training may increase respiratory muscle strength in the AVG group in our study.

Health status, families' overprotection, and disease burden may decrease PAL in children with CLD [40]. The effects of exercise training on PAL in PCD are uncertain. Cakmak et al. did not find the improvement in PAL after 8-week exercise training in a case with Kartagener syndrome [14]. Hebestreit et al. stated that there was no improvement in vigorous PAL in 6 months of unsupervised exercise training in the intervention group at the third and sixth months in CF patients. However, they found significant improvements in PA participation at 18th and 24th months [5]. In healthy children, 12 weeks of AVGs versus no intervention improved PAL after the training [41]. Maximum EE and total EE were higher during the training sessions in children with asthma in the AVG group compared to traditional exercise training group due to game type required full body movement and being interactive [12]. Children and adolescents have more difficulty gaining regular exercise than adults, and the type of exercise is vital to encourage them to be active [9]. Therefore, increased EE due to chosen games used full body movement in our study and increased PCD patients' participation and encouragement to do regular exercise due to being enjoyable, might have resulted in increase in PAL in the AVG group.

ADL decreases due to impaired PF, physical inactivity, and social isolation in children with CLD [3, 40], and ADL status is affected in PCD [3]. Although ADL limitation is reduced with aerobic exercise training in CF [42], the studies investigating the exercise training effects on ADL in PCD are scarce. Cardiorespiratory fitness is essential to perform the test as quickly as possible, and the shortening test duration indicates improved ADL level [3, 4]. We found that ADL test duration was decreased, and the change in SMO_2 improved in the AVG group compared to the controls. The improvements in PF, the ability to use oxygen, and respiratory and peripheral muscle strength after AVG training may be the reasons for improved ADL performance in PCD after the AVGs.

PCD negatively impacts the QOL's physical, emotional, social functioning, and treatment burden parameters [8]. There is a lack of data regarding the effects of exercise training on QOL in PCD. In CF, a home-based AVGs for 6 weeks increased QOL's physical functioning and respiratory symptom scores [10]. In another study, change in role limitation was positively correlated with change in PAL and maximal workload and embarrassment was positively associated with a change in FEV_1 and PAL after the exercise training [5]. We found that the PCD-QOL's physical, emotional, and social functioning; treatment burden; and upper and lower respiratory symptom parameters improved in the AVG group. The reasons for increased PCD-QOL's physical functioning and upper-lower respiratory symptom parameters in the AVG group may be improved PF, and increased respiratory and

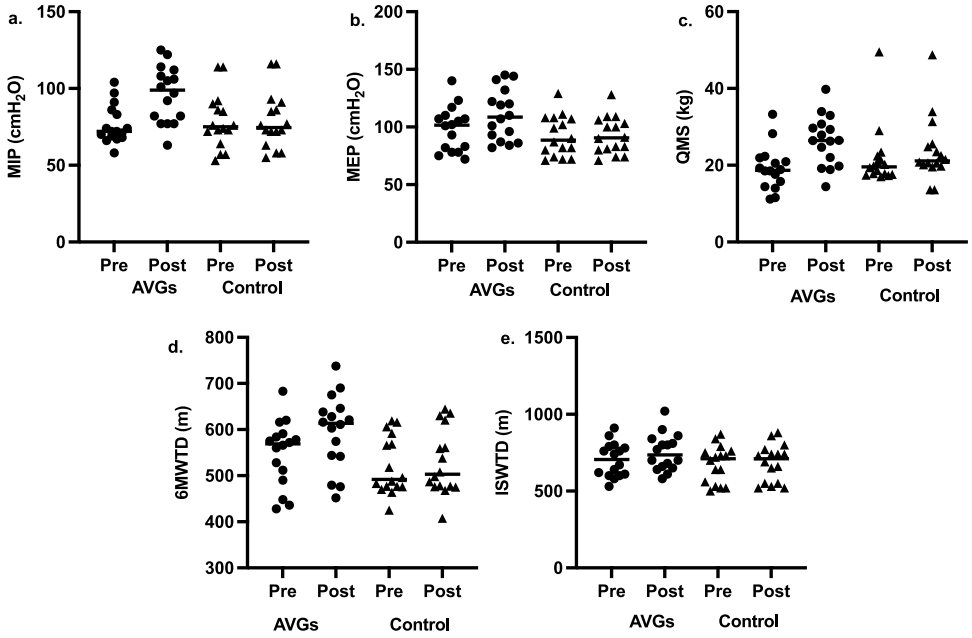

Fig. 3 Respiratory and peripheral muscle strength, distance of 6-min walk test, and incremental shuttle walk test in active video gaming group and control group pre- and post-treatment program. Abbreviations: MIP, maximal inspiratory pressure; MEP, maximal expiratory pressure; QMS, quadriceps muscle strength; 6MWD, six-minute walk test distance; ISWD, incremental shuttle walk test distance

peripheral muscle strength. Impaired social function incites the emotional function impairment in PCD [8]. Increased health status, PAL, and participation in independent or social activities might promote social and emotional functioning in the AVG group. We determined that the treatment burden of PCD-QOL was more improved in the AVG group than in the controls. Treatment burden is increased in PCD due to barriers to completing treatments such as being busy, forgetting about treatments, and losing motivation [9]. Increased motivation to do physiotherapy programs due to having fun with AVGs might improve the treatment burden score of PCD-QOL in the AVG group.

There is no clarity on which exercise training modality could be applied in physiotherapy management in PCD. This study's primary strength was that we demonstrated AVGs may be used as an alternative exercise training modality to improve pulmonary-extrapulmonary features, encouraging PCD patients to exercise regularly and be more active. Our findings may be guiding for health professionals to promote PAL and exercise interventions focusing on strength, aerobic fitness improvement, and decreasing participation limitation in circles of family and schools.

The study has a few limitations. The first limitation is the absence of a follow-up period. Although we planned to follow up long-term effects of AVGs on PCD, we could not perform the follow-up evaluations due to the COVID-19 pandemic to protect them from transmission risk. Secondly, we were unable to assess exercise capacity using cardiopulmonary exercise testing CPET), which is the gold standard. The effects of AVGs on respiratory, cardiac, and metabolic function in PCD might be observed more comprehensively using CPET.

Conclusion

In conclusion, this is the first study to determine whether 8-week moderate-intensity AVGs improve PF, respiratory and peripheral muscle strength, SMO_2, exercise capacity, PAL, ADL, and QOL in clinically stable PCD patients. The use of AVGs at home and in clinics has become popular due to the spread of technology, increasing clinical and affordable commercial availability of this system. The enjoyment of exercising using AVGs may positively affect exercise motivation and commitment. Moreover, the hands-free system of the device, which allows movement of all extremities without using a remote control, encourages movement.

AVGs may be preferable due to being enjoyable and providing visual-audial feedback in PCD. Further studies are required to determine long-term effects of AVGs.

Authors' contributions Hazal Sonbahar Ulu contributed tothe study conception and design, the acquisition of the data, analysis andinterpretation of the data, drafting the manuscript and approved the finalversion of the manuscript. Deniz Inal Ince contributed to the study conceptionand design, acquisition of data, analysis and interpretation of the data,drafting the manuscript, revising the manuscript for intellectual content, andapproved the final version of the manuscript. Melda Saglam contributed to thestudy conception and design, revising the manuscript for intellectual content,and approved the final version of the manuscript. Aslihan Cakmak contributed tothe acquisition of the data, drafting the manuscript and approved the finalversion of the manuscript.Naciye Vardar Yagli contributed to revising themanuscript for intellectual content, and approved the final version of themanuscript. Ebru Calik Kutukcu contributed to revising the manuscript forintellectual content, and approved the final version of the manuscript. ErkanSumer contributed to the acquisition of the data and approved the final versionof the manuscript. Ugur Ozcelik contributed to the acquisition of the data,revising the manuscript for intellectual content, and approved the finalversion of the manuscript.

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Declarations

Ethics Approval This present study was approved by Hacettepe University Clinical Research Ethics Committee (03/09/2018, KA180026).

Informed Consent PCD patients participated in our study and their families signed the written informed consent.

Competing interests The authors have no relevant financial or non-financial interests to declare.

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