REVISTA NEUROCIÊNCIAS

Original

Exergaming: Impact on Aerobic Capacity and Handgrip Strength in Autism Spectrum Disorder

Exergaming: impacto na capacidade aeróbica e força manual no Transtorno do Espectro Autista

Exergaming: Impacto en la Capacidad Aeróbica y la Fuerza de Prensión Manual en el Trastorno del Espectro Autista

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Resumo

Objetivo. Analisar os efeitos do *exergaming* na capacidade aeróbica, percepção de esforço, força de preensão manual e equilíbrio em indivíduos com Transtorno do Espectro Autista (TEA). **Método.** Foi realizado um ensaio clínico cruzado com 10 voluntários de ambos os sexos, diagnosticados com TEA (10,50±0,84 anos; Índice de Massa Corporal (IMC) =21,51±1,38kg/m²). Os voluntários foram randomizados em dois momentos de intervenção: *Exergaming* (EXE) e Sem Intervenção (WI), com um período de *washout* de um mês entre os cruzamentos dos momentos avaliados. O momento EXE consistiu em *exergaming* utilizando o Nintendo Wii®, com os jogos *Basic Run Plus* e *Mario Kart Wii*, duas vezes por semana, totalizando 10 sessões. Todos foram avaliados quanto à capacidade aeróbica por meio do teste de caminhada de 6 minutos (TC6), percepção de esforço pela Escala Modificada de Borg, equilíbrio postural na presença e ausência da visão utilizando a plataforma *Wii Balance Board*® (WBB) e força de preensão manual de ambas as mãos com um dinamômetro digital. **Resultados.** No momento EXE, foram observados aumentos na distância percorrida no TC6 ($p<0,001$) e na força de preensão manual (Direita: $p<0,001$; Esquerda: $p<0,001$) em comparação ao momento WI. No momento EXE, houve redução na percepção de esforço ($p=0,011$), sem alterações significantes nas variáveis de equilíbrio postural. **Conclusão.** Neste estudo, o momento EXE promoveu melhora na capacidade aeróbica, na força de preensão manual e na redução da percepção de esforço, sem alterar o equilíbrio postural de voluntários com TEA.

Unitermos. *Exergaming;* Transtorno do Espectro Autista; Capacidade aeróbica; Força de Preensão Manual

Abstract

Objective. To analyze the effects of exergaming on aerobic capacity, perceived exertion, and hand grip strength and balance in individuals with autism spectrum disorder (ASD). **Method.** We conducted a crossover clinical trial. A total of 10 volunteers of both sexes, diagnosed with ASD (10.50±0.84 years; Body Mass Index (BMI)=21.51±1.38kg/m^2). The volunteers were randomized into two intervention moments: Exergaming (EXE) and Without Intervention (WI)

and after one-month washout period of crossing of the evaluated moments. The EXE moment consisted of exergaming using the Nintendo Wii®, with the Basic Run Plus and Mario Kart Wii games, twice a week for 10 sessions. All volunteers were assessed for aerobic capacity through the 6-minute walk test (6MWT), perceived exertion using the Modified Borg Scale, postural balance in the presence and absence of vision using the Wii Balance Board® (WBB) platform, and the grip strength of both hands through the digital dynamometer. **Results**: At the EXE moment, were observed increases were observed in the distance in the 6MWT ($p<0.001$) and in the handgrip strength (Right: $p<0.001$; Left: $p<0.001$) compared to the WI moment. At the EXE moment, there was a reduction in perceived exertion ($p=0.011$), with no significant changes in postural balance variables. **Conclusion:** In this study, the EXE moment improved aerobic capacity, handgrip strength and reduced perceived exertion, without altering the postural balance of volunteers with ASD.
Keywords. Exergaming; Autism Spectrum Disorder; Aerobic Capacity; Handgrip Strength

Resumen

Objetivo. Analizar los efectos del *exergaming* sobre la capacidad aeróbica, la percepción del esfuerzo, la fuerza de prensión manual y el equilibrio en individuos con Trastorno del Espectro Autista (TEA). **Método.** Se llevó a cabo un ensayo clínico cruzado. Participaron un total de 10 voluntarios de ambos sexos, diagnosticados con TEA (10,50±0,84 años; Índice de Masa Corporal (IMC) =21,51±1,38kg/m²). Todos los voluntarios fueron asignados aleatoriamente a dos momentos de intervención: Exergaming (EXE) y Sin Intervención (WI), con un período de lavado (washout) de um mes antes del cruce entre los momentos evaluados. El momento EXE consistió en exergaming utilizando el Nintendo Wii®, con los juegos *Basic Run Plus* y *Mario Kart Wii*, dos veces por semana durante 10 sesiones. Todos los voluntarios fueron evaluados en cuanto a la capacidad aeróbica mediante la prueba de caminata de 6 minutos (6MWT), la percepción del esfuerzo mediante la Escala Modificada de Borg, el equilibrio postural en presencia y ausencia de visión utilizando la plataforma Wii Balance Board® (WBB), y la fuerza de prensión de ambas manos mediante un dinamómetro digital. **Resultados:** En el momento EXE, se observaron aumentos en la distancia recorrida en la 6MWT ($p<0,001$) y en la fuerza de prensión de la mano (Derecha: $p<0,001$; Izquierda: $p<0,001$) en comparación con el momento WI. En el momento EXE, hubo una reducción en la percepción del esfuerzo ($p=0.011$), sin cambios significativos en las variables de equilibrio postural. **Conclusión:** En este estudio, el momento EXE mejoró la capacidad aeróbica, la fuerza de prensión de la mano y redujo el esfuerzo percibido, sin alterar el equilibrio postural de los voluntarios con TEA.
Palabras clave. Exergaming; Trastorno del Espectro Autista; Capacidad Aeróbica; Fuerza de Prensión Palmar

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INTRODUCTION

Physical activity in children with autism spectrum disorder (ASD) has shown promise for improving quality of life[1-3]. Positive impacts on cardiorespiratory function and weight gain control have also been reported, given that these individuals have a relatively inactive lifestyle[4].

Some authors report that this population has difficulties in adhering to the practice of physical activities, causing limitations in carrying out conventional treatments, through physical exercises. Therefore, it becomes necessary to search for new exercise strategies that provide greater acceptance[5,6].

Taking this barrier into account, some efficient methods for treating autism are described in the literature using playful activities concomitant with therapeutic intervention, making use of visual materials and games for better understanding. In this sense, the use of exergaming can be a viable rehabilitation alternative for these individuals[7].

Exergaming is a therapeutic modality defined as the combination of physical exercise and video games. This equipment requires the performance of body movements and gestures, converting these real movements into the virtual realm. Exergaming can make the user become active, as it combines physical and mental exercises simultaneously, linking the movements of physical activity to the control of the video game, executing them in a playful and interactive way, which can provide better adherence to exercise[8]. Some studies used exergaming only as an intervention protocol for participants with ASD, achieving improvements in terms of behavioral control[9], executive functions[10], cognitive functions[11,12], and motor coordination[13], in addition to increasing physical fitness levels and decreasing body mass index (BMI)[4]. Thus, exergaming provides visual and auditory feedback that constantly stimulates the player during the activity, improving learning and performance[14].

In the literature, there are few clinical trials investigating the use of exergaming as an intervention to improve physical fitness. Moreover, the potential benefits of exergaming on physical components in individuals with ASD remain insufficiently explored, both in terms of the intervention itself and the methodological designs employed. These studies are typically described as quasi-experimental and controlled trials using parallel-group designs, in which participants are exposed to a single and distinct intervention[4,8,13,15]. Such study designs may reduce the efficiency of the trials and increase interindividual variability[14].

Given these limitations, the need for crossover study designs becomes evident. In crossover trials, the same participants receive two or more interventions in a randomized order, separated by a washout period to minimize potential residual effects[13,14]. One example of this study design was used in cancer patients who performed exergaming at different time points. This crossover trial showed reductions in self-reported fatigue, improvements in quality of life, and increases in dorsiflexor and plantar flexor muscle strength and endurance. These outcomes reinforce the potential of the crossover design to more accurately assess the effects of exergaming, including in populations such as individuals with ASD.

To date, no crossover studies have been identified that evaluate the effects of exergaming on physical fitness components in individuals with ASD. Therefore, the objective of this study was to analyze the crossover effect of exergaming on cardiorespiratory fitness, perceived exertion, handgrip strength and postural balance in individuals with ASD.

METHOD

Study design

The randomized crossover trial was conducted between October 2021 to August 2022. The study was approved by the Research Ethics Committee of the University of Sapucaí Valley's (Protocol n. 4.991.227) and registered in the Registration Platform of Clinical Trials (RBR-7yryyk7; http://www.ensaiosclinicos.gov.br/rg/?q= RBR-7yryyk7). All volunteers were informed of the procedures involved in the study; upon their agreement to participate, they signed an informed consent form.

Sample

Sample size and power were previously calculated through a pilot study. The calculation (G*Power 3.1.7; Franz Paul, Universität Kiel, Germany) of sampling power and effect size was obtained through fatigue subscale scores, using the following parameters: Test family: t-tests> Test statistical: means: difference between two independent means (two groups) > type of power analysis: a priori: calculate the required sample size – given α, power and effect size. The calculated sample presented the following results: (EXE=241.44±46.48m; WI=50.47±48.78; d=4.005; power=0.982), requiring a minimum of 6 volunteers.

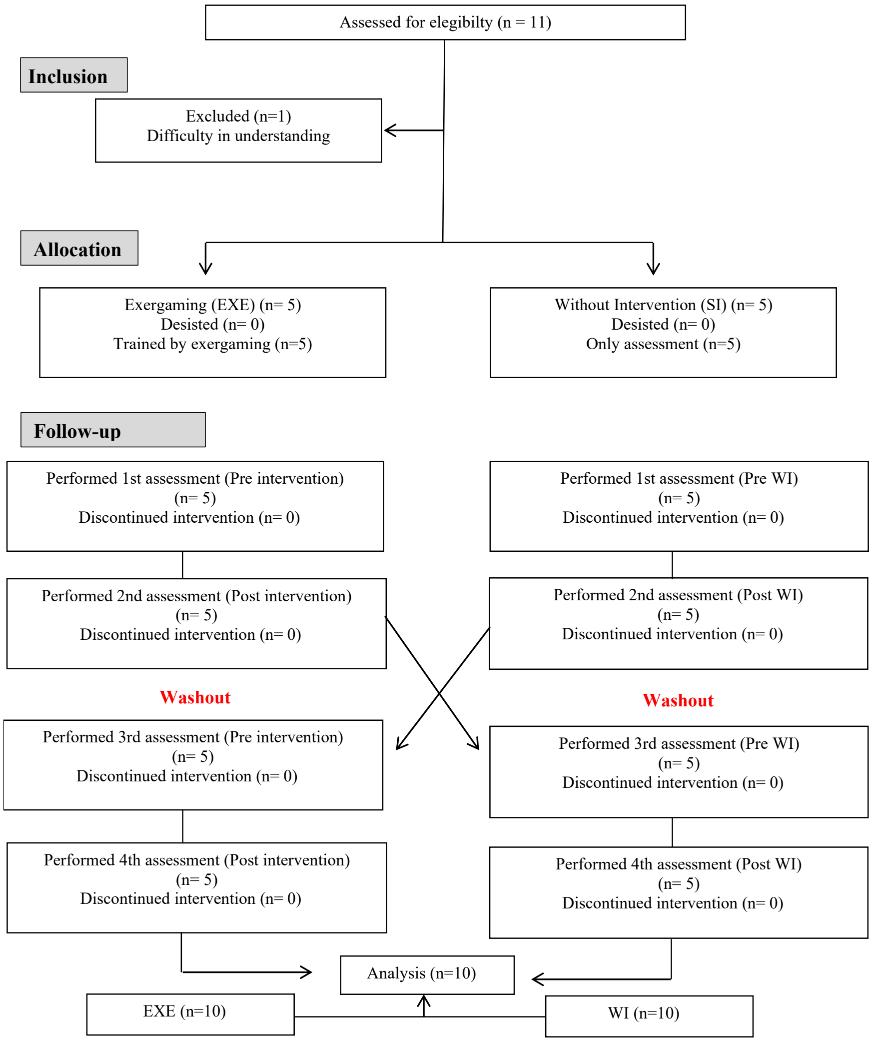
Procedure

A total of 10 volunteers diagnosed with mild to moderate autism spectrum disorder were eligible for the study, including males and females between the ages of 8 and 14 years who attended the Associação de Pais e Amigos dos Excepcionais (APAE), Borda da Mata city, Minas Gerais, Brazil, and with medical release to perform physical exercises.

This study excluded volunteers with severe ASD, subjects who had difficulties in carrying out the implementation of assessment and intervention instruments, those who disabling diseases that restrict movements with the upper and lower limbs, individuals with contraindications to the practice of physical exercises and those who could not participate in the study for personal reasons.

Before starting the study protocol, volunteers were randomized into two intervention moments: Exergaming (EXE) and Without Intervention (WI). At the EXE moment, the volunteers first received the intervention protocol for 10 sessions. At the WI moment, the volunteers performed only the evaluations. After completing the first phase, all volunteers performed one month of washout, preceded by the crossing as shown in Figure 1.

Figure 1. Study design.



Measures

All assessment and intervention procedures using exergaming were conducted at APAE in the city of Borda da Mata - Minas Gerais. All volunteers were assessed at the beginning and after 10 sessions. Assessments were performed according to the procedures described below.

Handgrip strength assessment

For all ASD volunteers, handgrip strength was measured using the handgrip dynamometer Instrutherm® digital, DM 90 model (Instrutherm Measuring Instruments Ltda., São Paulo, Brazil). The use of the digital handgrip dynamometer shows high correlation rates (r>0.72), for young and old people[16]. The volunteers were positioned as recommended by the American Society of Hand Therapists for measuring handgrip strength[17]. The volunteer was positioned seated with his back supported on the backrest, with ankles, knees and hips at 90º. The arm was positioned close to the trunk, with the elbow flexed at 90°, the forearm in a neutral position and the wrist positioned between 0° and 30° of extension. All volunteers received the same verbal and demonstrative instructions on how to use the equipment.

After the rest period, all volunteers were given the same verbal command "tighten the handle, squeeze, squeeze", to record handgrip strength values through a maximum voluntary isometric contraction (MVIC) using the handgrip dynamometer. Three measurements were taken on both hands. A one-minute rest interval was given between repetitions. The best handgrip measurement was considered for analysis. The values obtained were expressed in kilograms-force (kgf). The test was performed for both hands, before and after the EXE and WI moments.

Assessment of aerobic capacity and perceived effort

To assess aerobic capacity, the six-minute walk test (6MWT) was used. The 6MWT was performed following the standards established by the American Thoracic Society (2002)[18]. To do that, a stopwatch, measuring tape, oximeter, sphygmomanometer, and stethoscope were used. Vital signs such as heart and respiratory rate, systemic blood pressure, oxygen saturation, and perceived exertion by Modified Borg Scale were assessed before and after the test.

Before starting the test, the volunteer was instructed to rest for 10 minutes in a chair near the beginning of the walking route, while receiving test instructions. The examiner provided a demonstration, and each participant did a practice round before completing an attempt at the actual test. Volunteers were asked to walk as fast as they could until they were asked to stop. They were instructed not to worry if they needed to slow down or rest, but if they stopped, they should start walking again when they felt ready.

The test site was previously demarcated, considering a 30-meter path delimited by cones, and adhesive tapes on the floor corresponding to 5m. The volunteers were instructed to go around the cone and a counter was used to record the number of laps completed in the test. Volunteers were given the same instruction to begin the test with the verbal command "Start now or whenever you are ready." Every minute the same encouragement was given "You are doing a good job, and you have 5 minutes left".

After completing a six-minute walk, they were instructed to stop at the location and the examiner placed an adhesive tape on the floor, behind the volunteer's heel, indicating the place to stop and measured the distance from the last lap to the tape. Finally, the distance (in m) was recorded on the recording sheet and later transferred to the computer.

Perceived effort before and after performing the 6MWT was measured using the Modified Borg Scale. Each volunteer was instructed to indicate their perceived level of effort in the table at the end of each session. The intensity of perceived exertion was reported on a scale of 0 to 10 points (0, as no shortness of breath; 10, as maximum shortness of breath)[19]. This scale determines that the lowest score indicates the best effort condition.

Assessment of postural balance by Wii Balance Board

To assess postural balance, the WBB platform (Nintendo, Tokyo, Japan) was used. The platform presents a reliability index in test-retest analyses (ICC: 0,62-0,94)[20].

The volunteers were instructed to remain in orthostatism and a neutral resting position, in bipedal support on the WBB platform, with an intermalleolar distance of 10 cm using a template positioned between the feet. From this position, the volunteer was instructed to keep their gaze directed at a fixed target, corresponding to the height of each volunteer's eyes. The target distance was standardized to minimize interference with the visual condition on postural stability[20]. The volunteers were previously familiarized with the tests, in the presence and absence of vision. To assess balance with eyes closed, volunteers were positioned on the WBB platform, and a blindfold was placed over their eyes during collection.

The results obtained from postural balance in the two visual conditions using the WBB platform were expressed as a percentage of the distribution of the center of body mass in relation to the right and left sides. The balance assessment consisted of three collections, lasting 30 seconds, with a minute of rest between each collection[20].

Exergaming protocol

The exergaming protocol was performed in the Associação de Pais e Amigos dos Excepcionais, Borda da Mata, Minas Gerais, Brazil, which equipped with portable projectors and Nintendo Wii® consoles (Nintendo, Tokyo, Japan). The study used the game Wii Fit Plus and Mario Kart Wii (Nintendo, Japan). All ASD volunteers participated in exergaming sessions twice a week, for 10 sessions, with a weekly volume of approximately 90 minutes. The duration of training per week considered the individuality and tolerance of each individual to perform the intervention with exergaming. In addition, this study also sought to meet the individual needs of each volunteer. During the intervention period, perceived exertion was measured using the Modified Borg Scale and if an extreme exertion was reported, the intervention was suspended[15].

The chosen games within “Wii Fit Plus” were “Basic Run Plus”, and Mario Kart Wii. The goal of the Basic Run Plus is to run a route and reach the finish line. The game simulates running, a condition determined by game, performing lowers limbs movements. aimed to promote an increase in physical conditioning, consequently increasing aerobic capacity and improving postural balance.

After completing the first task of the intervention protocol, the Mario Kart Wii game was included. A Wii Kart accessory steering wheel was made available to the volunteer, which they had to hold firmly with their hands to perform upper limb movements to control the kart on a racetrack predetermined by the game, and must cross the finish line in the shortest possible time. The objective of choosing the game was aimed at improving upper limb mobility and handgrip strength to hold the steering wheel.

Statistical analysis

For statistical analysis of the data, the Statistical Package for the Social Sciences (SPSS; IBM Corp., Chicago, USA), version 20.0, was used. To test the normality of the data, the Shapiro-Wilk test was used, considering $p > 0.05$ as normal distribution.

To compare the differences of each EXE (pre and post) and WI (pre and post) moment, the data were submitted to the paired t-test if the sample presented normal distribution, otherwise, the data were submitted to the Wilcoxon test. In addition, to analyze the differences in means obtained between the EXE and WI moments, the data were submitted to the independent t-test in case of normal distribution, otherwise, the data was submitted to the Mann-Whitney test[15].

The effect size (Cohen's d) between the EXE and WI moments was obtained using the G*Power 3.1.7 software, complying with the following parameters: Values equal to and greater than 0.8 represent a large effect size; values between 0.8 and 0.2 represent medium effect size values; and values below 0.2 represent a small effect size[21]. In all analyses, a significance level of 5% was considered.

RESULTS

The sociodemographic and clinical characteristics of the sample of the present study are presented in Table 1.

The values obtained for handgrip, postural balance with eyes open and closed using the WBB platform, 6MWT distance covered, and perceived exertion using the modified Borg scale are presented in Table 2. At the EXE moment, there was an increase in handgrip values (Left=6.04±2.38kgf; $p<0.001$; Right=5.18±2.73kgf; $p<0.001$), in the distance covered in the 6MWT (241.44±46.48m; $p<0.001$), and a reduction in the scores on the modified Borg scale (-2.70±2.66; $p=0.011$). At the WI moment, the left handgrip strength showed an increase (0.62±0.85kgf; $p=0.048$) and 6MWT showed an decrease in the distance covered (-50.47±48.78m; $p=0.010$). At the EXE moment, increases in handgrip strength of both hands, respiratory capacity and reduced perception of effort in the ASD volunteers were observed when compared to the WI moment. At the EXE and WI moments, no changes in postural balance were observed in either visual condition, as assessed by the WBB platform. In addition, the EXE moment showed a large effect size for the analyzed variables (Table 2).

Table 1. Clinical and sociodemographic characteristics of the volunteers at baseline.

	Results
Age (years)	10.50±0.84
Body mass (kg)	46.53±4.40
Height (m)	1.46±0.04
BMI (kg/m^2)	21.51±1.38
Sex – n(%)	
Male	7 (70)
Female	3 (30)
Level of ASD – n(%)	
Level 1	7 (70)
Level 2	3 (30)
Exergaming protocol (x/week)	2.00
Training volume (time per week)	90.36±21.23

BMI: Body Mass Index; ASD: Austism Spectrum Disorder; kg: Kilogram (kg); m: meters; kg/m^2: Kilograms per square meter; n: Sample number; %: Percentage; x/ week: times a week

DISCUSSION

The ASD has shown a significant increase in incidence[22]. Studies show that these individuals present deficits in social interaction, communication, motor skills, fitness, cognitive and executive funtions, motor coordination, restricted and repetitive interests, and emotional reciprocity deficits[5-8,23].

Table 2. Comparative analysis of mean values, standard error, mean difference, standard deviation and 95% confidence interval (95% CI) of palmar grip of both hands, percentage of center of gravity with eyes open and closed using the Wii Balance Board (Nintendo Wii), distance covered in the 6-minute walk test (6MWT) and perceived exertion using the modified BORG scale, assessed in volunteers with ASD, in moments of exergaming (EXE) and without intervention (WI).

Variables	EXE (n= 10)				WI (n= 10)				EXE vs WI p-value	ES
	Pre (0 session)	Post (10th session)	Mean difference±SD	p-value*	Pre (0 session)	Post (10th session)	Mean difference±SD	p-value#		
Left handgrip strength (kgf)	10.99 (1.33)	17.03 (1.79)	6.04±2.38 (-0.85 - 14.27)	<0.001	11.55 (1.73)	12.17 (1.67)	0.62±0.85 (4.96 - 17.33)	0.048	<0.001	3.032
Right handgrip Strenght (kgf)	12.23 (1.64)	17.41 (2.11)	5.18±2.73 (-1.23 - 11.97)	<0.001	12.05 (1.73)	12.04 (1.79)	-0.01±0.52 (-11.25- 14.82)	0.953	<0.001	2.641
COG Wii EO Left (%)	52.91 (2.44)	52.46 (1.51)	-0.44±4.62 (-1.09 - 21.70)	0.765	53.76 (4.18)	56.12 (3.59)	2.35±15.33 (-12.37 - 9.54)	0.639	0.586	0.241
COG Wii-EO Right (%)	47.15 (2.43)	49.23 (1.57)	2.08±4.81 (4.04 - 22.95)	0.204	47.75 (4.07)	43.54 (3.59)	-4.20±13.22 (3.63 - 27.86)	0.341	0.174	0.631
COG Wii-EC Left (%)	53.68 (2.81)	53.67 (1.18)	-0.00±5.95 (2.73 - 17.88)	0.996	53.16 (4.37)	55.80 (5.14)	2.63±16.08 (-6.43 - 7.09)	0.616	0.631	0.178
COG Wii EC Right (%)	45.91 (2.94)	46.42 (1.16)	0.50±6.43 (-17.99 - 4.57)	0.808	46.64 (4.32)	43.28 (3.04)	-3.35±16.37 (-14.17 - 7.09)	0.533	0.491	0.309
6-MWT (m)	476.89 (26.30)	718.34 (29.39)	241.44±46.48 (-0.85 - 14.27)	<0.001	520.81 (36.87)	470.34 (30.58)	-50.47±48.78 (-0.85 - 14.27)	0.010	<0.001	4.008
BORG	6.80(0.66)	4.10 (0.60)	-2.70±2.66 (-0.85 - 14.27)	0.011	6.90 (0.78)	5.70 (0.63)	-1.20±3.19 (-0.85 - 14.27)	0.265	0.269	0.511

* paired t-test; # independent t-test. EXE: Exergaming; WI: Without intervention; ES: Effect Size; SD: Standard Deviation; COG: center of gravity; EO: eyes open; EC: eyes closed; %: percentage; 6-MWT: six-minute walk test.

Another factor that appears to affect motor skills is associated with a relatively inactive lifestyle, as a decrease in physical fitness and muscular strength has been observed due to motor deficits and impairments in postural balance[24], leading to inability or difficulty in performing more complex motor skills which are necessary in various physical and sporting activities, resulting in low adherence to physical exercise[11,25]. Studies show that individuals with ASD tend to prioritize video games for exercise and play more frequently[7,9,26]. Therefore, the use of this tool is suggested as it is a viable and appropriate alternative for practicing physical exercises in this individuals[11]. The exergaming protocol using the Nintendo Wii® for individuals with ASD promoted improvement in physical and functional condition. After 10 sessions, there was an increase in handgrip strength and distance covered in the 6MWT, associated with a reduction in perceived exertion using the modified Borg Scale, showing a rise in physical fitness and improvement in cardiorespiratory capacity.

The results of this study show an improvement in aerobic capacity and handgrip strength after exergaming. It is possible that the protocol used seems to induce adaptation in the pulmonary, cardiovascular and neuromuscular systems, generating improvements in the supply of oxygen to the mitochondria and in the metabolic control of muscle fibers[27]. In addition, it can be seen that at the WI moment, there was a reduction in the distance covered on the 6MWT, highlighting that the that the regular practice of exergaming seems to be an important factor for these individuals, in which the activities encourage players to constantly improve their performance[11] and facilitate motor learning[10,12,23].

Additionally, exergaming provides feedback on participants' physical fitness through scoring and verbal command[2]. Another factor to be considered to improve these variables may be associated with repeating video games during the sessions, which may have promoted improvement in motor and memory areas, cognitive functions, with positive effects on behavior[11], although we have not evaluated.

For postural balance with the WBB platform, no significant differences were found after the intervention period, suggesting that the intervention models adopted in the study were not sufficient to promote changes in postural balance variables. It is understood that the improvement in physical fitness obtained in this study may have led to neuromuscular system adaptations, as well as at the supraspinal and spinal levels, which modify muscle spindle sensory impulses and the excitability of peripheral nerves in order to influence motor responses in postural balance[28]. As a consequence, the orthostatic position in double support and static requires low levels of muscle contraction and the adoption of balance control strategies[29], associated with factors such as visual feedback, lack of anteroposterior oscillation parameters and oscillation area and time predetermined by the WBB platform, may have limited the obtaining of oscillation parameters of the center of mass, not allowing improvements in postural balance variables to be evidenced at the EXE and WI moments. Therefore, assessment protocols and the choice of games to stimulate postural control need to be considered.

The improvement of physical fitness is recognized as a factor correlated with increased quality of life. As happens with children with typical development, regular physical activity in children and adolescents with ASD shows lower blood pressure levels, greater bone density, and a reduction in BMI, when compared to sedentary individuals. Furthermore, physical exercise has a beneficial effect on psychological health, improvements in social behavior, reduction of stereotypical behaviors, and increased academic performance[1,4,8].

Handgrip strength represents several indices of physical function, predicting disability, morbidity, mortality, and dependence in activities of daily living, in addition to being an indicator of quality of life. Our findings show that the improvement in handgrip strength observed in ASD individuals may be associated with the exergaming protocol that requires grip and pinch. In this sense, specific training for the upper limbs suggests an essential component for the execution of functional motor tasks and quality of life[30].

The crossover study proved to be effective in assessing the effects of interventions at two moments. Furthermore, a washout period was important to help eliminate possible residual effects of an intervention[14]. It is notable that in the EXE moment, there was an increase in aerobic capacity and effort tolerance. However, at the WI moment, it was also possible to observe a reduction in the distance covered in the 6MWT and in handgrip strength. With the crossover study design, it demonstrates that not exercising for one to two weeks leads to a reduction in physical fitness levels, such as cardiorespiratory capacity and muscular strength[15]. Therefore, the results of this study suggest maintaining a continuous physical activity program for individuals with ASD.

This study has some limitations. Firstly, although the sample power was satisfactory, we highlight that there was difficulty in recruiting volunteers with ASD, due to the study period being carried out during the COVID-19 pandemic. As a result, sanitary measures made difficult access to the institutions that served these volunteers, as well as being far from the place where the study was carried out. The fact that we are not in a large city reduced the number of volunteers and the predominance of males. In addition, the gender distribution of the sample reflects current epidemiological data, which indicate a higher prevalence of ASD among men compared to women. Another limitation may be associated with the use of the WBB platform, where visual feedback, the absence of anteroposterior oscillation measurements, and the collection time pre-determined by the equipment. Another factor to be considered is performance assessment, as it is associated with learning retention through scores obtained in games, which were not evaluated. These characteristics should be taken into account when interpreting the results and generalizing the conclusions.

CONCLUSION

In this study, the EXE moment promoted improvements in aerobic capacity, as evidenced by an increase in the distance covered in the 6MWT, enhanced handgrip strength in both hands, and reduced perceived effort, without altering postural balance variables in children and adolescents with

ASD. Although the study demonstrated benefits in this population, the continuation of physical interventions is recommended to further improve the functional capacities of these individuals. Additionally, future studies with larger and more heterogeneous samples are needed to confirm and generalize the observed effects.

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REFERENCES

1.Ferreira JP, Ghiarone T, Junior CRC, Furtado GE, Carvalho HM, Rodrigues AMM, *et al*. Effects of physical exercise on the stereotyped behavior of children with autism spectrum disorders. Medicina 2019;55:685-703. https://doi.org/10.3390/medicina55100685

2.Huang J, Du C, Liu J, Tan G. Meta-Analysis on intervention effects of physical activities on children and adolescents with autism. Int J Environ Res Public Health 2020;17:1950. https://doi.org/10.3390/ijerph17061950

3.Ji C, Yang J, Lin L, Chen S. Executive function improvement for children with autism spectrum disorder: a comparative study between virtual training and physical exercise methods. Children (Basel) 2022;9:507. https://doi.org/10.3390/children9040507

4.Dickinson K, Place M. A Randomised control trial of the impact of a computer-based activity programme upon the fitness of children with autism. Autism Res Treat 2014;2014:419653. https://doi.org/10.1155/2014/419653

5.Must A, Phillips S, Curtin C, Bandini LG. Barriers to physical activity in children with autism spectrum disorders: relationship to physical activity and screen time. J Phys Act Health 2015;12:529-34. https://doi.org/10.1123/jpah.2013-0271

6.Bossink LWM, van der Putten AA, Vlaskamp C. Understanding low levels of physical activity in people with intellectual disabilities: A systematic review to identify barriers and facilitators. Res Dev Disabil 2017;68:95-110. https://doi.org/10.1016/j.ridd.2017.06.008

7.Fang Q, Aiken CA, Fang C, Pan Z. Effects of exergaming on physical

and cognitive functions in individuals with autism spectrum disorder: a systematic review. Games Health J 2019;8:74-84. https://doi.org/10.1089/g4h.2018.0032
8.Anderson-Hanley C, Tureck K, Schneiderman RL. Autism and exergaming: effects on repetitive behaviors and cognition. Psychol Res Behav Manag 2011;4:129-37. https://doi.org/10.2147/PRBM.S24016
9.Hilton CL, Cumpata K, Klohr C, Gaetke S, Artner A, Johnson H, *et al*. Effects of exergaming on executive function and motor skills in children with autism spectrum disorder: a pilot study. Am J Occup Ther 2014;68:57-65. https://doi.org/10.5014/ajot.2014.008664
10.Yu CCW, Wong SWL, Lo FSF, So RCH, Chan DFY. Study protocol: a randomized controlled trial study on the effect of a game-based exercise training program on promoting physical fitness and mental health in children with autism spectrum disorder. BMC Psychiatr 2018;18:1-10. https://doi.org/10.1186/s12888-018-1635-9
11.Rhodes RE, Warburton DE, Bredin SS. Predicting the effect of interactive video bikes on exercise adherence: An efficacy trial. Psychol Health Med 2009;14:631-40. https://doi.org/10.1080/13548500903281088
12.Caro K, Tentori M, Martinez-Garcia AI, Alvelais M. Using the FroggyBobby exergame to support eye-body coordination development of children with severe autism. Int J Hum Comput Stud 2017;105:12-27. https://doi.org/10.1016/j.ijhcs.2017.03.005
13.Senn S. Crossover trials in clinical research. 2nd ed. Hoboken: John Wiley & Sons, Ltd.;2002. https://doi.org/10.1002/0470854596
14.Nolan SJ, Hambleton I, Dwan K. The Use and reporting of the cross-over study design in clinical trials and systematic reviews: a systematic assessment. PLoS One 2016;11:e0159014. https://doi.org/10.1371/journal.pone.0159014
15.Silva Alves R, Carvalho JM, Borges JBC, Nogueira DA, Iunes DH, Carvalho LC. Effect of exergaming on quality of life, fatigue, and strength and endurance muscle in cancer patients: a randomized crossover trial. Games Health J 2023;12:358-65. https://doi.org/10.1089/g4h.2022.0161
16.Lee SC, Wu LC, Chiang SL, Lu LH, Chen CY, Lin CH, *et al*. Validating the capability for measuring age-related changes in grip-force strength using a digital hand-held dynamometer in healthy young and elderly adults. BioMed Res Int 2020;2020:6936879. https://doi.org/10.1155/2020/6936879
17.Mathiowetz V, Weber K, Volland G, Kashman N. Reliability and validity of grip and pinch strength evaluations. J Hand Surg Am 1984;9:222-6. https://doi.org/10.1016/s0363-5023(84)80146-x
18.American Thoracic Society/European Respiratory Society international multidisciplinary consensus classification of the idiopathic interstitial pneumonias. Am J Respir Crit Care Med 2002;165:277–304. https://doi.org/10.1164/ajrccm.165.2.ats01
19.Burdon JGW, Juniper EF, Killian KJ, Hargreave FE, Campbell EJ. The perception of breathlessness in asthma. Am Rev Respir Dis 1982;126:825-8. https://doi.org/10.1164/arrd.1982.126.5.825

20.Clark RA, Bryant AL, Pua Y, McCrory P, Bennell K, Hunt M. Validity and reliability of the Nintendo Wii Balance Board for assessment of standing balance. Gait Posture 2010;31:307-10. https://doi.org/10.1016/j.gaitpost.2009.11.012
21.Cohen J. Statistical power analysis for the behavioral sciences, 2nd ed. New York: Lawrence Erlbaum Associates, Pub; 2013. https://doi.org/10.4324/9780203771587.9
22.Matson JL, Kozlowski AM. The increasing prevalence of autism spectrum disorders. Res Autism Spectr Disord 2011;5:418-25. https://doi.org/10.1016/j.rasd.2010.06.004
23.Ludyga S, Pühse U, Gerber M, Mücke M. Muscle strength and executive function in children and adolescents with autism spectrum disorder. Autism Res. 2021;14;2555-63. https://doi.org/10.1002/aur.2587
24.Ansari S, Hosseinkhanzadeh AA, AdibSaber F, Shojaei M, Daneshfar A. The Effects of aquatic versus kata techniques training on static and dynamic balance in children with autism spectrum disorder. J Autism Dev Disord 2021;51:3180-6. https://doi.org/10.1007/s10803-020-04785-w
25.Getchell N, Miccinello D, Blom M, Morris L, Szaroleta M. Comparing energy expenditure in adolescents with and without autism while playing Nintendo® Wii(™) Games. Games Health J 2012;1:58-61. https://doi.org/10.1089/g4h.2011.0019
26.Mazurek MO, Engelhardt CR. Video game use in boys with autism spectrum disorder, ADHD, or typical development. Pediatrics 2013;132:260-6. https://doi.org/10.1542/peds.2012-3956
27.Hassanlouei H, Falla D, Arendt-Nielsen L, Kersting UG. The effect of six weeks endurance training on dynamic muscular control of the knee following fatiguing exercise. J Electromyogr Kinesiol 2014;24:682-8. https://doi.org/10.1016/j.jelekin.2014.06.004
28.Taube W, Gruber M, Gollhofer A. Spinal and supraspinal adaptations associated with balance training and their functional relevance. Acta Physiol Oxf Engl 2008;193:101-16. https://doi.org/10.1111/j.1748-1716.2008.01850.x
29.Di Giulio I, Maganaris CN, Baltzopoulos V, Loram ID. The proprioceptive and agonist roles of gastrocnemius, soleus and tibialis anterior muscles in maintaining human upright posture. J Physiol 2009;587:2399-416. https://doi.org/10.1113/jphysiol.2009.168690
30.Alaniz ML, Galit E, Necesito CI, Rosario ER. Hand strength, handwriting, and functional skills in children with autism. Am J Occup Ther 2015;69: 6904220030p1-9. https://doi.org/10.5014/ajot.2015.016022