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Research article

Adolescents with hemophilic knee arthropathy can improve their gait characteristics, functional ability, and physical activity level through kinect-based virtual reality: A randomized clinical trial

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ABSTRACT

Background: Hemophilic arthropathy is caused by recurrent intra-articular bleeding, most commonly in the knee joints. In terms of physical impact, this arthropathy causes significant disability and hampers the physical activity and functionality of he affected individuals.
Objective: This study intended to examine the effect of a physical rehabilitation program incorporating Kinect-based virtual reality (KBVR) on gait characteristics, functional ability, and physical activity level in adolescents diagnosed with hemophilic knee arthropathy (HKA)
Materials and methods: In a randomized clinical trial, 56 boys, aged 10–14 years, with moderate HKA, were randomly allocated into two groups. The control group (n = 28) received conventional physical therapy (CPT), while the KBVR group (n = 52) received a 30-min KBVR exercise program in addition to the CPT. Training was conducted three times/week for 12 successive weeks. Gait characteristics (step length, cadence, velocity, peak knee extension moment during stance, and knee flexion amplitude during swing) were assessed using a gait analysis system, the functional ability was assessed through the 6-min walk test, and physical activity level assessed by the Adolescents' Physical Activity Questionnaire on the pre- and post-treatment occasions.
Results: The KBVR group achieved more favorable changes in the gait characteristics [step length (P = 0.015), cadence (P = 0.004), velocity (P = 0.024), peak knee extension moment during stance (P = 0.018), and Knee flexion amplitude during swing (P = 0.032)], functional capacity (P = 0.002), and physical activity levels (P = 0.007) compared to the control group.

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Conclusion: The use of KBVR exercises within a rehabilitation program is a potentially effective therapeutic option for the total care of adolescents with HKA.

1. Introduction

Hemophilia is a six-linked inherited clotting condition marked by recurrent bleeding episodes resulting from a deficiency in the blood clotting factor. This deficiency involves either factor VIII (hemophilia A) or factor IX (hemophilia B), with more tendency toward hemophilia A, which affects 1 in every 5000 live male births, whereas hemophilia B affects about 1 in every 30,000 live male births [1]. The severity and recurrence of bleeding in hemophilic children are inversely related to the extent of deficiency in clotting factors. For children with severe hemophilia, the clotting factor level is less than 1%. Moderate severity will be prominent if the factor activity falls between 1 and 5%, whereas mild if the factor activity is greater than 5% [2].

Hemophilia is commonly associated with musculoskeletal hemorrhage, which can occur either spontaneously or as a consequence of minor trauma. Most bleeding occurs within the joints, a condition commonly referred to as hemarthrosis, with a predominant occurrence observed in the lower extremity joints, particularly the knees and ankles. This preference for these specific joints is attributed to increased weight-bearing pressure and stress while standing and walking [3,4]. Recurrent bleeding episodes within the same joint eventually result in consequences of pathological events including progressive enlargement of the synovial lining, the deposition of hemosiderin, cartilage deterioration, and alterations in the subchondral bone structure. These hemosiderin deposits can provoke additional synovial enlargement and swelling, contributing to degenerative and chronic joint degeneration (hemophilic arthropathy) [5]. The repetition of hemarthrosis episodes leads to the emergence of a degenerative and irreversible condition called hemophilic arthropathy. Consequently, hemophilic arthropathy is characterized by persistent pain, diminished joint mobility, muscle atrophy, and other associated biomechanical changes and, eventually, gait problems [6].

While children are more frequently energetic than grownups, hemophilic children are in danger of decreased physical activity levels and sedentary lifestyles due to parental or medical restrictions. Also, repeated bleeding and hemarthrosis can lead to muscle weakness, joint contracture, diminished functional ability, and reduced physical fitness, eventually leading to decreased activity levels [7,8]. In moderate hemophilia, motor impairments (such as joint pain/swelling, reduced mobility, muscle weakness/atrophy, balance/coordination disturbance, and gait deviations) are generally less severe than in severe hemophilia. With appropriate treatment and management, individuals with moderate hemophilia can lead relatively normal lives, including participating in physical activities with caution and proper safety measures to minimize the risk of bleeding or joint damage during physical activities [9].

Previous studies compared the temporal-spatial, kinetic, and kinematic characteristics of level walking in children and adolescents with hemophilic lower limb arthropathy and their age-matched, typically developing counterparts [10–13]. According to these studies, young and adolescent boys with hemophilia receiving prophylactic treatment showed differences in their walking parameters. They showed increased swing and decreased stance, longer single support times and shorter double support times, and slower walking velocity when compared to typically developing peers [10,11]. Further, children and adolescents with hemophilia displayed significant changes in gait's kinetic and kinematic parameters. They showed greater knee flexion during the entire gait cycle, increased knee flexion, and reduced knee extension moment during the stance phase [11–13].

Presently, the evidence from a recent systematic review demonstrates that they have lower exercise capacity when compared to reference values for the 6-min walk test or maximum oxygen uptake [14]. The promotion and prescription of physical exercise for patients with hemophilia should emphasize enhancing muscle strength, flexibility, and physical function, either on their own or when combined with complementary treatments such as laser therapy, have shown promise in benefiting children and adults with hemophilia [15,16]. The usage of virtual reality (VR) in clinical practice as an alternative to conventional procedures has recently sparked the interest of physical rehabilitation professionals. Virtual reality (VR) is a type of computer technology that provides simulated sensory feedback to allow children to participate in activities and events that are comparable to those they could face in real life. It has been used therapeutically to enhance strength, range of motion, coordination, mental concentration, balance, and gait [17]. To our knowledge, there has been inadequate research on how KVG-VR exercises affect children with hemophilia, despite the fact that the role of VR exercises has been studied in adults with hemophilic arthropathy [18–20]. The goal of this study was, therefore, to look into changes in gait parameters, functional ability, and physical activity level in hemophilic adolescents after a 12-week kinetic-based virtual reality (KBVR) exercise program administered to adolescents with hemophilic knee arthropathy (HKA).

2. Materials and methods

2.1. Study design

This randomized clinical trial was carried out at the Prince Sattam bin Abdulaziz University (PSAU) outpatient physical therapy clinic of the college of Applied Medical Science. Ethical approval has been granted by the Physical Therapy Research Ethics Committee at PSAU (No: RHPT/0021/0023). The study was registered in the Clinicaltrials.gov Registry (No: NCT05802368). A simple demonstration of study procedures was given to children and their parents prior to study enrollment, and a consent form was requested to be signed by parents once they accepted their children's participation. All study procedures were in agreement with the ethical standards of the Declaration of Helsinki 1975. Prior to and after the treatment, data on gait characteristics, functional ability, and physical activity level were collected by an independent researcher who was unaware of the treatment assignment of the study's participants.

2.2. Subjects

Fifty-six boys with HKA were selected from Maternity and Child Hospital, King Khalid Hospital, and other referral institutions in Alkharj, Saudi Arabia. Children have been included according to these criteria: their ages 10 and 14, with moderate hemophilia (factor VIII concentration 0.01–0.05 $IU.mL^{-1}$) [21], bilateral involvement of knee joints (knees were "target joints" and had 4 bleeding episodes over the previous six months) [22], received replacement therapy with factor VIII concentrates, medically stable (i.e., take stable doses of medications, and had no plan for change types and dosages of these medications during the study period), ensure the factor level before assessment to avoid spontaneous joint or muscle bleeding during the test or the plan and drop out during the program, had no persistent disabling pain, and had no consolidated contractures or congenital anomalies. Exclusion criteria were children with severe hemophilia, recent bleeding episodes for at least three months before initial assessment, severe radiological abnormalities such as bone erosions, degeneration, bone ankylosis, or joint subluxation (verified by the radiological Petterson score of hemophilic arthropathy) [23], engagement in a regular exercise program in the past six months, and the unwillingness to stick to the training schedule.

2.3. Assignment procedure

The participants were divided into two treatment groups at random; KBVR combined with physical exercises (KBVR group; $n = 28$), or physical exercises alone (Control group; $n = 28$). An independent researcher conducted a simple randomization procedure. Participants were given a series of numbers ranging from 1 to 56, after which a web-based research randomizer was used to produce two equal subsets of these numbers, which were then assigned to the treatment arms at random [24].

3. Outcome measures

3.1. Primary outcome measures

3.1.1. Gait analysis

A valid and reliable three-dimensional gait analysis system (Vicon Motion Systems Ltd, Oxford, England) was used for gait analysis [25]. Each participant was prospectively instructed about the testing procedures and familiarized in a pre-testing session. A mid-gait protocol was used to record three attempts. Each participant was instructed to walk bare at a comfortable, self-selected speed along a 10-m walkway. At the same time, the trajectories of reflective markers and forces were recorded through 12 optoelectronic cameras with a 120-Hz sampling rate and two force plates at 1000 Hz.

Fifteen reflective markers (10 mm diameter) were applied on common anatomical landmarks through the use of double-face adhesive tape. One on the sacrum and bilaterally on the following points: anterior superior iliac spine, mid-thigh, lateral to the knee (directly lateral to the axis of rotation), middle tibia (the middle point between the knee marker and the lateral malleolus), lateral malleolus, and heel and forefoot between the second and third metatarsal heads [26–28]. For this study, we collected and analyzed some gait characteristics: spatiotemporal (step length, cadence, and velocity), kinetic (peak knee extension moment during the stance phase), and kinematic (knee flexion amplitude during the swing phase). The Python open-source library, pyCGM2, was used for all data processing [29].

4. Secondary outcome measures

4.1. Functional ability assessment

The 6-min walk test was used to assess functional abilities in accordance with the international guidelines recommended by the American Thoracic Society and the European Respiratory Society [30]. It's a submaximal test that's been found to be helpful for children with persistent musculoskeletal problems [31], which is considered a valid and reliable tool for children with chronic conditions [32]. Participants were given 6 min to walk as far as they could down a 50-m straight path while the assessor carefully watched them with a timer. Participants were informed about the aim of the test and shown the start and endpoints before the measurement. They were advised not to hop, run, or leap in any way. At each assessment, all participants were subjected to a single test.

4.2. Physical activity level assessment

The Adolescents' Physical Activity Questionnaire (PAQ-A) in Arabic edition was used to measure the PALs. The validity of the PAQ-A in assessing general PALs in Arab adolescents has already been documented [33]. The PAQ-A is a nine-item, self-administered, seven-day memory questionnaire that evaluates the PALs in various settings, including athletics, physical education, and playtime following school, in the evening, and on weekends. The items on the questionnaire are graded on a 5-point Likert scale (1 [low PALs] and 5 [high PALs]). The average score of elements is used to compute the PAL summary score.

5. Intervention

5.1. Traditional physical therapy

Before beginning the exercise program, we carefully documented participants' prophylaxis usage as a factor in designing their exercise prescriptions. We considered factors such as timing and dosage of treatments to minimize the bleeding risks associated with exercising. To ensure safety, we closely monitored pain thresholds throughout the exercise sessions; participants were instructed to report any discomfort or pain they experienced during the exercises.

Over 12 weeks, patients in both groups were given three 30-min physical therapy exercise programs each week. The program aimed to control pain, maintain/regain flexibility, improve gait characteristics, promote functional ability, and increase overall physical activity level. The following exercises were included in the program:

Gentle stretching exercises include hip flexors, knee flexors, anterior tibial group, and calf muscles. It consisted of a 20-s stretch followed by a 20-s relaxation, which was done five times every session for each muscle [34]. Mild resistance exercises that targeted muscle groups in the lower extremities were done five times per session, with a 5-s contraction followed by a 5-s relaxation. We utilized a combination of types of resistance, such as resistance bands, free weights, and bodyweight exercises [35]. Based on the interest of each individual, a brisk walking program on a treadmill or usage of a stationary bicycle/stair stepper (∼10–15 min) [36].

A home program was devised to encourage regular exercise based on each subject's capacity. Participants were advised to conduct self-stretching activities and conditioning routines (walking outside for 15 min) on days when they did not visit the facility for treatment [37].

5.2. Kinect-based virtual reality

The KBVR group joined a 30-min VR-based training session utilizing Kinect Xbox (Fig. 1), after the session of traditional physical therapy. The device has an infrared camera sensor (Kinect sensor) that detects the participant's movement in actual time. While the user's movement is not correctly achieved in the game's setting, the user receives visual and auditory sensory feedback about the motion faults. A television monitor was placed in a noiseless location, and the gaming device's infrared camera sensor was placed in front of the monitor. The participant was about 1.5–2 m away from the monitor. The investigator adjusted the location of the sensor whereas the participant stood before the beginning of the training session to confirm the ideal place and motion capture, and loaded games into the system. Following the completion of the setup, the research assistant demonstrated games from the rehabilitation program. Soccer, skiing, and football were among the games used for training. All games were provided to pique participant's interest in the subjects. and necessitated the use of one's lower extremities. Each game was played for 10 min during the 30 min of training. During a game, the participant may see a virtual avatar on the monitor, and the avatar moves in the same manner as the participant. To get a high score in the game, the participant had to control his movements by watching the avatar's movements. The child was informed of the previous section's game score and stimulated to update the current score in the succeeding sector of the game. The research assistant supervised the participants during training to ensure their safety. Participants in the KBVR programs typically performed active hip flexion, hip abduction, hip external and internal rotation, knee flexion and extension, ankle dorsiflexion, and plantarflexion while standing.

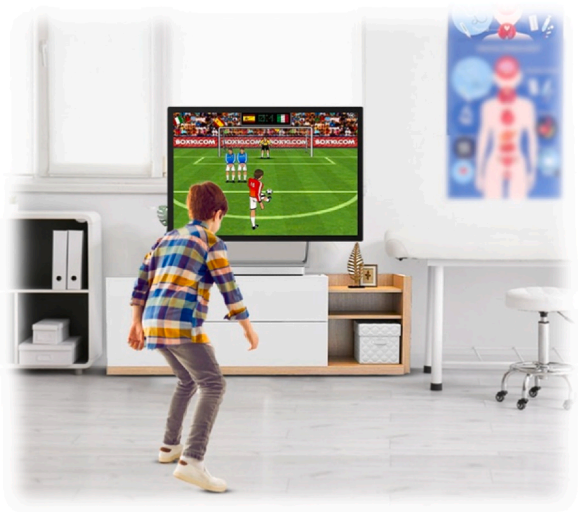

Fig (1). KBVR exercise.

5.3. Sample size

Using the G-power software (version 3.1.9.2, Dusseldorf, Germany), a priori power analysis was used to establish the appropriate sample size. The analysis was based on two independent means and pooled standard deviation of the pea knee extension moment during stance phase (mean 1 = 0.63 Nm/kg, mean 2 = 0.54 Nm/kg, pooled SD = 0.11 Nm/kg), which were obtained from a pilot study (unpublished) including eight children with HKA who received the same interventions employed in the present study (i.e., four children for each intervention; KBVR vs traditional physical therapy). The analysis revealed that a sample size of 50 boys (50 boys total) was required to achieve a statistical power of 80.91% with a 0.05 alpha. However, a larger sample size of 56 boys (28 per group) was used to adjust for potential dropout rates.

5.4. Statistical analysis

For all statistical tests, we used SPSS v24 (SPSS Inc., Chicago, IL). The Shapiro-Wilk test was used to assess the normality of the data. The unpaired *t*-test, Man Whitney *U* test, and Chi-square test were respectively used to compare the baseline continuous, ordinal, and nominal data between the study groups.

The two-way repeated-measure ANOVA test was used to calculate change differences (pre-to-post) in primary and secondary outcome measures between the study groups. If a significant treatment-by-time interaction was indicated, the paired *t*-test was used to calculate the change within each group. The partial eta-squared (partial η^2) and Cohen's d (mean difference/standard deviation of the difference) (were respectively used to calculate the effect size where the ANOVA test or the paired *t*-test indicated a statistically significant between- or within-group difference. A P-value <0.05 was considered significant in all tests.

6. Results

Fifty-six boys with hemophilic arthropathy (out of 81 potentially eligible boys) were suitable for the study and were randomly assigned to the KBVR group or the control group (28 boys for each group). Four boys (one from the KBVR group and three from the

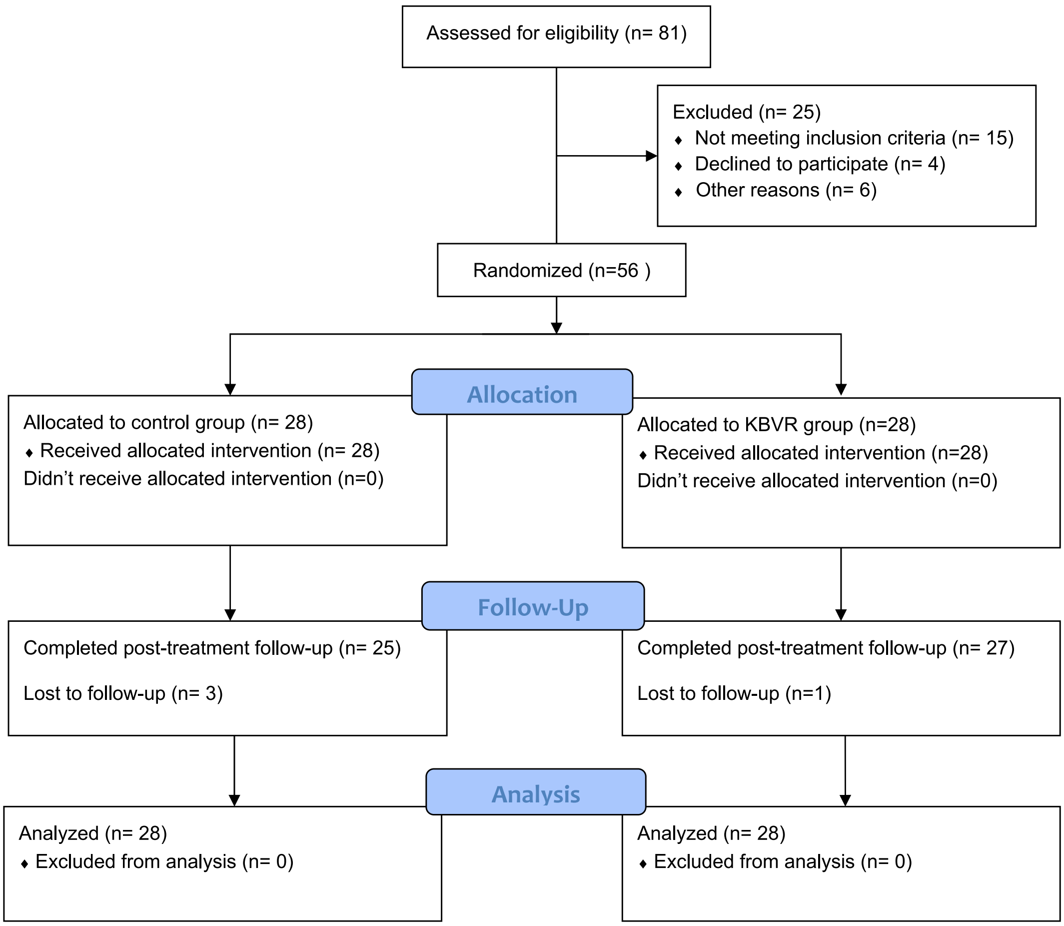

Fig. 2. Participants' CONSORT flowchart.

control group) were unable to finish the treatment program or the post-treatment measurements because of schedule conflicts or unknown causes (Fig. 2). However, their data were handled through a regression imputation approach and used in the analyses in compliance with the intention-to-treat principle.

Characteristics of the study groups are demonstrated in Table 1. Participants of the KBVR and control groups were similar in terms of age and anthropometric variables (height, weight, and BMI) at the baseline ($P > 0.05$). Also, the clinical (pain characteristics, use of analgesics, and physical activity levels) and radiological status (i.e., Pettersson score) for the knee joint were not different among both groups ($P > 0.05$).

Participants in the KBVR and control groups had comparable adherence-to-treatment rates (i.e., the proportion of the 36 training sessions that were planned over a 12-week period have actually been completed.) ($P = 00.11$). The KBVR group's median (min-max) adherence-to-treatment rate was 90.3 % (83.3 %–100 %), compared to the control group's 88.9 % (80.6 %–97.2 %).

Changes in gait characteristics are demonstrated in Table 2. The analysis revealed a significant moderate treatment-by-time interaction effect on the spatiotemporal [step length: $F_{(1,54)} = 6.34$; $P = 0.015$; partial $\eta^2 = 0.11$; cadence: $F_{(1,54)} = 8.97$; $P = 0.004$; partial $\eta^2 = 0.14$; walking velocity: $F_{(1,54)} = 5.38$; $P = 0.024$; partial $\eta^2 = 0.09$], kinetic [peak knee extension moment during the stance phase: $F_{(1,54)} = 5.93$; $P = 0.018$; partial $\eta^2 = 0.10$], and kinematic [knee flex amplitude during the swing phase: $F_{(1,54)} = 4.86$; $P = 0.032$; partial $\eta^2 = 0.08$] gait variables. The KBVR group participants demonstrated more favorable changes (i.e., longer step length, higher walking speed, cadence, and knee extension moment during the stance, and larger knee flexion amplitude during the swing) in comparison with those of the control group.

Changes in PALs are shown in Fig. 3. The pre-treatment median (IQR) of the PAL was 3.1 (2.6–3.2) for the VR group and 2.8 (2.4–3.1) for the control group, while the post-treatment median (IQR) of the PAL was 3.6 (3.2–3.8) for the VR group and 3.1 (2.5–3.2) for the control group. The mixed ANOVA analysis demonstrated a significant medium treatment-by-time interaction effect on the PALs [$F_{(1,54)} = 7.27$; $P = 0.007$; partial $\eta^2 = 0.13$]. The VR group reported greater increase of the PALs from the pre-to post-treatment occasion as compared to the control group.

Changes in PALs are shown in Table 3 and Fig. 3. The mixed ANOVA analysis demonstrated a significant medium treatment-by-time interaction effect on the PALs [$F_{(1,54)} = 7.27$; $P = 0.007$; partial $\eta^2 = 0.13$]. The KBVR group reported a greater increase of the PALs from the pre-to post-treatment occasion as compared to the control group.

Changes in functional ability are shown in Fig. 4. The pre-treatment mean (SD) 6-MWT distance was 449.68 (59.48) m for the KBVR group and 455.21 (65.47) m for the control group, while the post-treatment 6-MWT scores were 516.26 (70.81) m for the KBVR group and 471.43 (57.42) m for the control group. The analysis revealed a significant large treatment-by-time interaction effect on the 6-MWT distance [$F_{(1,54)} = 11.01$; $P = 0.002$; partial $\eta^2 = 0.17$]. The 6-MWT distance increased more significantly in the KBVR group in comparison with the control group.

Changes in functional ability are shown in Table 4 and Fig. 4. The analysis revealed a significant large treatment-by-time interaction effect on the 6-MWT distance [$F_{(1,54)} = 11.01$; $P = 0.002$; partial $\eta^2 = 0.17$]. The 6-MWT distance increased more significantly in the KBVR group from the pre-to post-treatment occasion in comparison with the control group.

7. Discussion

Adolescents with hemophilia frequently have recurrent bleeding, especially in the lower limb joints, which can result in joint hemarthrosis. Additionally, these adolescents are significantly less physically active than their healthy counterparts. This hemarthrosis may affect their gait characteristics, functional ability, and PAL when paired with insufficient exercise [37]. So, the present study was intended to look into the impact of KBVR on gait parameters, functional ability, and PAL in adolescents with HKA. The findings showed that, in comparison to the CPT program only, integrating KBVR exercises into the CPT led to more evident improvement in gait characteristics, functional ability, and PAL.

Table 1
The baseline demographic and clinical characteristics of participants in the KBVR and control groups.

Characteristics	KBVR group (*n* = 28)	Control group (*n* = 28)	Sig.
Age, *years*	12.46 ± 1.50 (10–14)	12.89 ± 1.19 (10–14)	0.24[a]
Height, *m*	1.35 ± 0.08 (1.21–1.53)	1.37 ± 0.07 (1.25–1.54)	0.27[a]
Weight, *kg*	40.43 ± 5.79 (31–53)	41.18 ± 4.32 (32–49)	0.59[a]
BMI, kg/m^2	22.10 ± 1.48 (19.56–24.33)	21.81 ± 1.20 (19.45–23.80)	0.44[a]
PA (>120 min/week), (Y/N), *n* (%)	6 (21.4)/22 (78.6)	9 (32.1)/19 (67.9)	0.55[c]
Pain on 30 m walking, M (IQR; min-max)	1 (0–2; 0–4)	2 (1–2.75; 0–5)	0.12[b]
Pain duration, *years*	3.89 ± 1.37 (1–6)	4.46 ± 1.29 (2–8)	0.11[a]
Analgesics use (Y/N), *n* (%)	3 (10.7)/25 (89.3)	5 (17.9)/22 (82.1)	0.71[c]
Radiological PS – knee sub-score, M (IQR; min-max)	2.8 (0–3.5; 0–5.5)	3.2 (0–3.70; 0–4.5)	0.62[b]

Data are expressed as mean ± standard deviation (data ranges) except for pain on 30 m walking and radiological PS scores are expressed as median (interquartile ranges; min-max scores) and data regarding physical activity practice and analgesics use are demonstrated as frequency (percentage). Sig: significance level at $p < 0.05$.

[a] Unpaired t-test.

[b] Mann Whitney U test.

[c] chi-square test, KBVR: Kinect-based virtual reality, BMI: body mass index, M (min-max): median (minimum-maximum), Y/N: yes/no, PA: physical activity; IQR: interquartile range, PS: Pettersson score (0–13 point).

Table 2
The comparison of changes in gait characteristics between the experimental (KBVR) and control groups.

	KBVR group (n = 28)	Control group (n = 28)	Treatment-by-time interaction	
			Sig.	Partial η^2
Step length, cm				
Pre	0.53 ± 0.07	0.52 ± 0.06	0.015*	0.11
Post	0.58 ± 0.06	0.54 ± 0.05		
Sig.	<0.001*	0.0001*		
Cohen's d	1.07	0.86		
Cadence, step/min				
Pre	62.39 ± 7.58	61.54 ± 6.26	0.004*	0.14
Post	68.75 ± 7.72	64.18 ± 5.63		
Sig.	<0.001*	0.0003*		
Cohen's d	1.13	0.77		
Walking velocity, m/sec				
Pre	1.13 ± 0.13	1.11 ± 0.11	0.024*	0.09
Post	1.22 ± 0.09	1.15 ± 0.10		
Sig.	<0.001*	0.006*		
Cohen's d	1.05	0.56		
Peak knee ext. moment during stance, Nm/kg				
Pre	0.54 ± 0.17	0.51 ± 0.14	0.018*	0.10
Post	0.68 ± 0.24	0.59 ± 0.13		
Sig.	<0.001*	0.0003*		
Cohen's d	1.27	0.78		
Knee flex amplitude during swing, degree				
Pre	36.21 ± 7.44	34.89 ± 4.84	0.032*	0.08
Post	41.75 ± 9.67	38.14 ± 5.92		
Sig.	<0.001*	<0.001*		
Cohen's d	1.29	0.95		

KBVR: Kinetic based virtual reality, ext.: extension, flex.: flexion, IC: initial contact.
Sig: significance level, Partial η^2: effect size for interaction effect, Cohen's d: effect size of the change within a group, * Significant at $p < 0.05$.

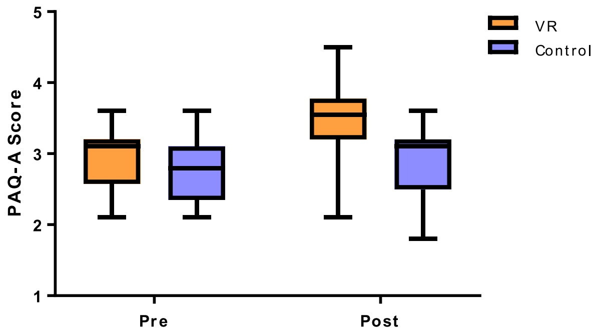

Fig. 3. This plot shows medians for the PALs on the pre- and post-treatment occasions in both groups, with colored bar bars showing the 1st quartile and 3rd quartile for each median and the error bar showing the maximum and minimum PALs scores.

Table 3
The comparison of changes in PALs between the KVG-VR) and control groups.

	KBVR**group (*n* = 28)**	**Control group (*n* = 28)**	Treatment-by-time interaction	
			Sig.	Partial η^2
Pre	3.1 (2.6–3.2)	2.8 (2.4–3.1)	0.007*	0.13
Post	3.6 (3.2–3.8)	3.1 (2.5–3.2)		
Sig.	<0.001*	0.47		
Cohen's *d*	0.99	0.13		

KBVR: Kinetic based virtual reality.
Data are expressed as median (interquartile ranges).
Sig: significance level, Partial η^2: effect size for interaction effect, Cohen's *d*: effect size of the change within a group, * Significant at $p < 0.05$.

These improvements may be attributed to many factors; the basic factor was the proper selection of an exercise program considering the participants' child preferences and physical abilities. Other factors may be children's interest, fun, and enjoyment during exercises since VR is used to create an interactive environment in rehabilitation programs to achieve different tasks and clinical

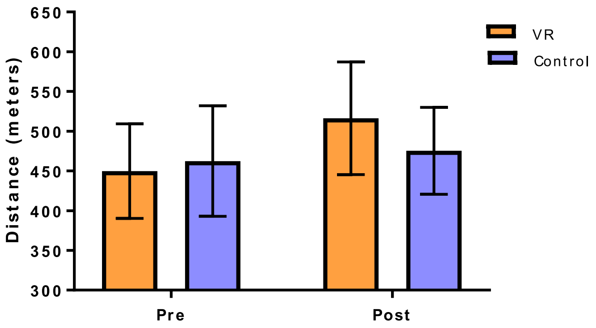

Fig. 4. This plot shows mean 6-MWT distance (m) on the pre- and post-treatment occasions for both groups, with colored bars showing the mean scores and the error bar representing standard deviations for each mean.

Table 4
The comparison of changes in functional ability (6-MWT distance, *m*) between the KBVR and control groups.

	KBVR group ($n = 28$)	Control group ($n = 28$)	Treatment-by-time interaction	
			Sig.	Partial η^2
Pre	449.68 ± 59.48	455.21 ± 65.47	0.002*	0.17
Post	516.26 ± 70.81	471.43 ± 57.42		
Sig.	<0.001*	0.008*		
Cohen's *d*	0.89	0.54		

KBVR: Kinetic based virtual reality.
Data are expressed as mean ± standard deviation.
Sig: significance level, Partial η^2: effect size for interaction effect, Cohen's *d*: effect size of the change within a group, * Significant at $p < 0.05$.

outcomes, the more task interactivity and task enjoyment, the greater the engagement of the patients in the task and improvement. In clinical rehab, VR techniques have achieved four major outcomes: motor re-learning and control, gait, strength, and postural control (balance) [38]. VR allows continuous practice and positive feedback to improve functional performance in everyday tasks. VR games often employ multisensory training at once, including visual, auditory, and even tactile, which give immediate feedback on the posture and movement. This multisensory training can activate neural networks connected to these senses, which enhances sensory-motor integration. This integration can lead to effective motor learning and enhance functional ability [39].

The current findings were supported by a study conducted by Belmont-Sánchez et al., who investigated the effect of VR on 11 pediatric patients with hemophilia and hemophilic arthropathy grade I and II and found that there was an improvement in global Gait Score in the form of a decrease in the support phase and right stride, and increase in cadence, step length, left stride and swing phase [40].

Furthermore, Howard's meta-analysis revealed that VR rehab programs are more successful than similar rehabilitation programs, as they can help improve strength, balance, and gait. These improvements may be attributed to increased patients' enthusiasm, physical adherence, and cognitive fidelity [41]. Furthermore, our findings were again in line with a study by Ucero-Lozano et al., who reported that immersive VR motion visualization helps in the reduction of joint discomfort. Additionally, Immersive virtual reality interventions can be an effective supplemental method for improving the joint condition and quadriceps strength in these patients [18]. Ucero-Lozano et al. observed that VR intervention can enhance ankle arthropathy patients' joint condition, pressure pain threshold, and range of motion [19].

In a study by Mirelman et al., which investigated the efficacy of the combination of a VR program with a standard treatment program for parkinsonism patients, it was concluded that adding VR to a treatment program has significantly improved some features of cognitive performance, physical function, and gait parameters [42]. In the current study, there were significant improvements in functional ability following rehabilitation via VR; these improvements may be attributed to optimization in biomechanical gait parameters, so walking became more efficient with less tendency to fatigue, which in turn has a positive impact on participant's ability to maintain overall functional ability. Also, improvements in gait biomechanics can lead to increased walling speed, which can lead to improved functional ability. Multiple previous studies have supported the beneficial effect of virtual reality-based therapy on enhancing functions since it encourages patients to stay focused while practicing movement and gives them more control over events than in real-life situations, whilst also allowing therapists to grade the assignment to the proper level of difficulty and modify training intensity [43–45].

Our findings are consistent with those of Fontoura et al., who investigated the impact of VR on functional capacity and quality of life in individuals with Parkinsonism disease (PD); it was concluded that combining VR with traditional physical therapy can help people with Parkinson's disease improve their functional capacity and quality of life, demonstrating that exercise not only improves physical fitness but also improves the participant's interaction with the environment during daily activities [46]. Furthermore, VR has been utilized in rehabilitation as a facilitator of physical activity, with the idea that the user is immersed in an environment that simulates pleasant, familiar, or innovative audio/visual stimuli. The additional psychological advantages associated with its use boost the likelihood of long-term fitness program adherence. It also gives a feeling of regulated competition, which leads to a more satisfying exercise experience in general [47,48]. Our findings backed up Guixeres et al.'s conclusion that participants liked the idea of mixing physical exercise with the VR platform as a type of treatment and that this strategy increased physical activity [49]. In addition, the findings of this study are consistent with those of Evans, who reported that active VR games can trigger varied levels of physical activity intensity in young healthy individuals. As a result, active VR games could be a fun and different way to get some exercise [50].

The present study has some limitations, the first of which is the lack of control for the child's PAL outside the clinic, and changes in the child's daily physical activities including house chores were not recorded, unmonitored activities may affect the generalization of data, Consequently, more researches are needed with more comprehensive activities monitoring. Also, the assessment of PALs is done only through a self-reported questionnaire that may present a response bias or inaccuracy, furthermore, the self-assessment questionnaire may not detect the objective change in pain or joint health, so further research is needed using more objective methods like a pedometer or an accelerometer. This study focused only on measures related to activity and function. Therefore, future studies should consider including additional assessment tools for gauging potential changes in pain and joint health, which will provide a more comprehensive picture of the treatment effectiveness and broader implications of the results. The study only focused on adolescents between the ages of 10 and 14 years, generalizing the results is difficult as different age groups may respond differently to the treatment plan, and further research is required to look at the impact on various age groups. The findings are unlikely to apply to mild or severe cases of hemophilia because the present study only looked at a moderate type of the condition. Therefore, more research is needed to ascertain the effects of KBVR training combined with CPT program on kids' adolescents with mild and severe hemophilia.

8. Conclusion

Integrating KBVR exercises into the physical rehabilitation program for adolescents with HKA may improve their gait characteristics and increase their functional capacity. It is also likely to improve their PAL. However, more rigorous methodology-based controlled studies are required to validate its efficacy, with a particular emphasis on more reliable assessments of the PAL.

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Institutional review board statement

The study was conducted in accordance with the Declaration of Helsinki, and approved by the physical therapy research ethics committee at PSAU (No: RHPT/0021/0023). The study was registered in the Clinicaltrials.gov Registry (No: NCT05802368).

Informed consent statement

Informed consent was obtained from all subjects involved in the study.

Data availability statement

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

CRediT authorship contribution statement

Alshimaa R. Azab: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Methodology, Investigation, Formal analysis, Conceptualization. **Ragab K. Elnaggar:** Writing – review & editing, Supervision, Methodology, Formal analysis. **Ghfren S. Aloraini:** Visualization, Data curation. **Osama R. Aldhafian:** Writing – original draft, Resources, Data curation. **Naif N. Alshahrani:** Writing – original draft, Resources. **FatmaAlzahraa H. Kamel:** Writing – review & editing, Writing – original draft, Validation, Project administration, Conceptualization. **Maged A. Basha:** Writing – review & editing, Visualization, Software, Project administration. **Walaa E. Morsy:** Writing – original draft, Formal analysis, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e28113.

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