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ORIGINAL ARTICLE

Virtual reality based rehabilitation in adults with chronic neck pain: a systematic review and meta-analysis of randomized clinical trials

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Abstract

Chronic neck pain is one of the most frequent musculoskeletal disorders, with high prevalence worldwide. Rehabilitation is an essential component of therapeutic strategy. Virtual reality based rehabilitation (VRBR) is a powerful distraction technique that could be beneficial for chronic neck pain patients. The objective of this systematic review was to analyse the effectiveness of VRBR in chronic neck pain treatment. We followed the PRISMA guidelines and used four databases (CINAHL, Medline (Via PubMed), Scopus and Web of Science) from their inception to August 2023. Eligibility criteria were established using PICOS. Methodological quality was evaluated with the Downs and Black scale and the risk of bias with the Revised Cochrane risk-of-bias tool. The meta-analysis was performed using the RevMan software. Six studies were included in the systematic review and the meta-analysis. We observed significant differences in favour of VRBR for pain intensity (SMD = −0.46; 95% CI = −0.74, −0.19; p = 0.001), disability (MD = −2.84; 95% CI = −4.23, −1.45; $p < 0.0001$), global perceived effect (MD = 0.49; 95% CI = 0.25, 0.72; $p < 0.0001$) and patient satisfaction (MD = 0.62; 95% CI = 0.38, 0.86; $p < 0.00001$). However, at short-term follow-up significant differences were only obtained for disability (MD = −3.52; 95% CI = −5.85, −1.20; p = 0.003). VRBR can significantly improve pain intensity, disability, global perceived effect and patient satisfaction. The small number of articles included in the analysis is a limitation, even considering the good methodological quality of these studies. Investigating the effects of VRBR on mid and long-term follow-up and exploring different types of VR are needed. *PROSPERO database, registration number ID*: CRD42020222129.

Keywords Chronic neck pain · Virtual reality · Rehabilitation · Physical therapy · Disability

1 Introduction

Neck pain is one of the most frequent musculoskeletal disorders (Kazeminasab et al. 2022) with a high prevalence around the world (Kazeminasab et al. 2022; De Campos et al. 2018). Among all musculoskeletal disorders, neck pain is fourth in the most common worldwide (Verhagen et al. 2021). In 2017, the global prevalence was 288.7 million cases (Safiri et al. 2020). The origin of neck pain can be due to several causes. However, the cause is usually unknown and, in the absence of any identifiable cause, most of the people are diagnosed as having nonspecific neck pain (Blanpied et al. 2017; Farrell et al. 2019). There is a tendency for neck pain to become chronic (Kazeminasab et al. 2022). It is essential to find an appropriate treatment for this important health problem.

There are different therapeutic strategies for chronic neck pain treatment (Kazeminasab et al. 2022). Manual therapy, mobilisation and manipulation, laser therapy, acupuncture, dry needling and therapeutic exercise are some examples of non-pharmacological approaches to treat chronic neck pain (Kazeminasab et al. 2022; Blanpied et al. 2017). Clinical practice guidelines have supported a multimodal approach

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within a biopsychosocial framework where therapeutic exercise is an essential part of the therapeutic strategy (Blanpied et al. 2017; Bier et al. 2018). Different types of exercise have been recommended (Blanpied et al. 2017). According to Gross et al. (Gross et al. 2016), specific strengthening exercises combined with endurance or stretching exercises may be beneficial in reducing pain and improving functionality. However, other reviews (Blanpied et al. 2017; Parikh et al. 2019) and clinical practice guidelines (Bier et al. 2018) established that there is no agreement on what type of exercise is the most effective. Additionally, the effectiveness of rehabilitation depends on the level of adherence (Bailey et al. 2020). However, adherence is challenging, because therapeutic exercises are often considered monotonous and boring (Fang et al. 2020). Pain-related fear is a common behaviour in patients with chronic neck pain and it is associated with avoidance of physical exercise and consequently poor treatment adherence (Gava et al. 2022; Nijs et al. 2013). Moreover, treatments in patients with chronic pain must be followed lifelong (Navarro-Albarracin et al. 2018). Therefore, it is necessary to determine an effective intervention for this type of patients.

During the last decade, the use of new technologies, such as virtual reality (VR) has extended to clinical medicine (Li et al. 2017). Ivan Sutherland described VR as "*a window through which a user perceives the virtual world as if looked, felt, sounded real and in which the user could act realistically*" (Sutherland et al. 1965; Cipresso et al. 2018). In general, we can define VR as any device that provides stimuli on a monitor, such as video games consoles. The term VR is not confined to a particular hardware or software (Trost et al. 2015) and includes various technological devices and systems with different characteristics (Dominguez-Tellez et al. 2020). VR systems have been combined with computers, mobile applications and commercial devices (e.g. Nintendo Wii) (Pereira et al. 2020; De Miguel-Rubio et al. 2020). VR depends on the degree of immersion, that is, the feeling of "being present" in the virtual environment. It can be immersive, semi-immersive or non-immersive (Cipresso et al. 2018; Rutkowski et al. 2020). We can also distinguish between *"specialized"* VR (i.e. VR systems specifically developed for therapeutic purposes) and gaming VR (i.e. commercial VR-game consoles) (Rutkowski et al. 2020).

VR has been used in pain management in different populations (Smith et al. 2020; Kulkarni et al. 2020; Lauwens et al. 2020) and the results suggested its usefulness in treating pain-related problems. Effects have also been explored in physical rehabilitation (Dominguez-Tellez et al. 2020). VR based rehabilitation (VRBR) is a relatively recent approach (Corbetta et al. 2015) but it presents some advantages over the limitations of therapeutic exercise mentioned above. Among the proposed mechanisms, the first is distraction. VRBR is a powerful distraction technique as it directs the attention of the patient to an external stimulus rather than pain or body movement (Pereira et al. 2020). Therefore, VRBR can be beneficial to avoid some pain-related problems such as kinesiophobia and inactivity (Lopez-de-Uralde-Villanueva et al. 2016; Vlaeyen et al. 2012). The second mechanism is gamification, which is defined as *"the use of game design elements in non-game contexts"* (Johnson et al. 2016; Pereira et al. 2020). Gaming VR incorporates motivational features such as feedback, interactive elements, goal-setting and prevents monotony and boredom. Patients are involved in their recovery in an active way, increase their motivation and improve adherence to treatment (Johnson et al. 2016; De Miguel-Rubio et al. 2020; Pereira et al. 2020). VR devices combined with other game development techniques allow manipulating the content duration, intensity and feedback to create an adequate exercise prescription (Dominguez-Tellez et al. 2020; Pereira et al. 2020). In addition, the repetitive elements are thought to be a key mechanism that promotes learning (Kato et al. 2010). Finally, VRBR enables patients to perform challenging exercises in a safe environment (Kwon et al. 2023). Patients gain confidence in their ability to exercise and increase their physical activity, which can alter the perception of pain in patients during rehabilitation (Kantha et al. 2023). Moreover, compared to conventional rehabilitation, VRBR is considered cost-effective (Li et al. 2017).

In the available evidence, we found several systematic reviews (Goudman et al. 2022; Grassini et al. 2022) exploring the effects of VRBR in chronic pain management. Goudman et al. (2022) reported significant pain relief and improvements in functioning. This shows that VRBR has applications beyond the treatment of acute pain. Two other systematic reviews (Gava et al. 2022; Kantha et al. 2023) investigated VRBR effects in chronic musculoskeletal pain, including chronic neck pain patients. VRBR demonstrated pain reduction in these patients (Kantha et al. 2023) and improved pain-related fear (Gava et al. 2022). In addition, VRBR helps patients maintain their motivation during rehabilitation. However, the findings on different types of immersion remain unclear (Kantha et al. 2023). About chronic neck pain, Gumaa et al. (2019) concluded that the effectiveness of VRBR is promising. However, Ahern et al. (2020) reported that statistically but not clinically significant effects of VRBR were found for chronic neck pain. Furthermore, they referred to the need for higher quality studies. Recently, Gavish et al. (2023) reported that VR software invokes movements that were identified as fit for neck rehabilitation, with no adverse events. Erdogan et al. (2023) developed a VR system that demonstrates benefits in adherence to treatment and in checking the correct performance of the exercises in neck pain patients. Guo et al. (2023) explored the VRBR effects in patients with neck pain. They concluded that evidence support VRBR as a beneficial nonpharmacological approach to reduce pain intensity in patients with neck pain, specially in chronic neck pain. However, the high heterogeneity of the studies included in Guo et al. (2023) limits their findings.

Considering the multiple consequences of chronic pain and its relevance to public health, performing a systematic review devoted to chronic neck pain patients is needed. Besides, a subgroup analysis based on VRBR interventions is necessary to know whether VRBR alone or combined with other interventions result in a different yield. Moreover, there is an absence of solid conclusions regarding the type of VR used; it would be interesting to investigate the effects of VR depending on the level of immersion so we considered all types of VR. Finally, it is relevant to analyse the effects in the short, mid and long term due to the nature of chronic pain.

Consequently, the purpose of this systematic review and meta-analysis of randomized clinical trials (RCTs) was to analyse the effectiveness of VRBR in the treatment of chronic neck pain.

2 Materials and methods

2.1 Design

This systematic review was carried out according to the guidelines of The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) (Page et al. 2021). We established the following PICO question: “Is VRBR effective in the treatment of adults with chronic neck pain compared with other interventions?” Therefore, we performed a systematic review in order to identify RCTs exploring the effects of VRBR for chronic neck pain treatment.

2.2 Search strategy

The search was conducted in four databases (CINAHL, Medline (Via PubMed), Scopus and Web of Science) from their inception to January 2022 without language restrictions. An updated search was also conducted on the 7th of August 2023. "Appendix 1" describes the full search strategy. In an attempt to find other relevant articles, we also reviewed the reference list of other reviews and related articles.

Additionally, we conducted a search for ongoing RCTs in three clinical trial registries (ClinicalTrials.gov, the International Clinical Trials Registry Platform (ICTRP) and the International Standard Randomized Controlled Trial Number (ISRCTN) Registry). The search strategy used in each registry is described in "Appendix 2".

2.3 Study selection

The selection of studies was conducted systematically based on the prespecified PICOS criteria: Participants: adults (≥ 18 years) with chronic neck pain (12 weeks or more) (Furlan et al. 2015); Interventions: VRBR alone or combined with other interventions; Comparisons: no intervention, interventions without VRBR, standard treatment, usual care, or control; Outcomes: pain intensity and other outcomes related to pain; Study design: RCTs. Articles were excluded if they were non-peer-reviewed publications or considered as grey literature. Full texts in English, Spanish or French were included.

We used Mendeley Reference Manager (Mendeley Desktop, London, UK) in order to identify articles, check the duplicates and standardize the references. Two independent reviewers (BBG and ALG) performed the search, screened study titles and abstracts and assessed the full text of studies. Studies that did not meet inclusion criteria were excluded. We emailed corresponding author of the study if full text was not available. A third reviewer (ITS) was consulted in case of disagreements.

2.4 Data extraction

The following data were recorded from the included articles: References, country, disease, severity, sample size, age (years), gender (percentage of males), outcome measures, measuring instrument, time points assessment and quality (score obtained on the Downs and Black scale). Table 1 summarizes this information. Characteristics of interventions are shown in Table 2: References, interventions, session duration, frequency, program duration, supervision and adverse events.

Two independent reviewers (BBG and ALG) performed the data extraction. We emailed corresponding author of the study if information was insufficient or unclear. If information remained unavailable or if contact was not possible, it was analysed using the available data. A third reviewer (ITS) was consulted in case of disagreements.

2.5 Methodological quality

The methodological quality was evaluated with the Downs and Black quality assessment method (Downs et al. 1998). This scale consists of 27 items divided into 5 sections: study quality, external validity, study bias, confounding and selection bias and study power. We used the modified Downs and Black scale. The score range is 0–28. Higher values indicate a better methodological quality (Torres-Sanchez et al. 2019; Silverman et al. 2012). Studies can be categorized

Table 1 Characteristics of the included studies

References	Country	Disease	Severity (inclusion criteria)	Sample size	Age (years) Mean ± SD	Gender (% Males)	Outcome measures	Measuring instrument	Time points assessment	Quality
Bahat et al. (2015)	Australia	Chronic neck pain (≥ 3 months)	NDI greater than 10%	n = 32 EG: 16 CG: 16	EG: 40.63 ± 14.18 CG: 41.13 ± 12.59	EG: 37.5 CG: 31.25	Pain intensity	VAS	Pre-intervention Post-intervention 3 months follow-up	21
							Disability associated with neck pain	NDI		
							Kinesiophobia	17-TSK		
							Cervical kinematics: ROM; Vpeak; Vmean; TTP%; sway; accuracy	VR system		
							GPE	GPE Scale		
							Patient satisfaction	11-NRS		
							Exercise compliance	4-points scale		
							Static balance	Computerized stable platform		
							Functional balance	SLS and step test		
Bahat et al. (2018)	Australia	Chronic neck pain (≥ 3 months)	NDI greater than 12% + VAS during recent week than 20 mm	n = 90 EG1: 30 EG2: 30 CG: 30	Median (Q1, Q3) EG1: 48 (38.5, 57.5) EG2: 48 (35.5, 59) CG: 48 (35, 59)	EG1: 37 EG2: 30 CG: 23	Pain intensity	VAS	(Intervention) Pre-intervention Post-intervention 3 months follow-up (Control) Pre-intervention Post-intervention	19
							Disability associated with neck pain	NDI		
							Kinesiophobia	17-TSK		
							Cervical kinematics: velocity, TTP%, NVP, accuracy error, ROM	VR system		
							GPE	GPE Scale		
							Patient satisfaction	11-NRS		
							Exercise compliance	Diary/VR computers		
							Health status	EQ-5D		
Rezaei et al. (2019)	Iran	Nonspecific chronic neck pain (≥ 3 months)	A score ≤ 15 and ≥ 9 on NDI	n = 44 EG: 22 CG: 22	EG: 36.19 ± 9.80 CG: 31.23 ± 9.49	EG: 57.1 CG: 47.6	Pain intensity	VAS	Pre-intervention Post-intervention 5 weeks follow-up	24
							Disability associated with neck pain	NDI		
							Dynamic balance	YBT		

Table 1 (continued)

References	Country	Disease	Severity (inclusion criteria)	Sample size	Age (years) Mean ± SD	Gender (% Males)	Outcome measures	Measuring instrument	Time points assessment	Quality
Tejera et al. (2020)	Spain	Nonspecific chronic neck pain	-	n = 44 EG: 22 CG:22	EG: 32.72 ± 11.63 CG: 26.26 ± 9.21	EG: 50 CG: 45.5	Pain intensity	VAS	Pre-intervention Post-intervention 1 month follow-up 3 months follow-up	23
							Disability associated with neck pain	NDI		
							Kinesiophobia	11-TSK		
							ROM	ROM device		
							CPM	Algometer		
							TS	Algometer		
							Pain catastrophizing	PCS		
							Fear and avoidance beliefs	FABQ		
							PPT	Algometer		
							Pain-related anxiety	PASS-20		
Nusser et al. (2021)	Germany	Non-traumatic chronic neck pain (≥ 3 months)	-	n = 55 EG1: 17 EG2: 18 CG: 20	EG1: 51.2 ± 8.8 EG2: 53.1 ± 5.7 CG: 49.8 ± 8.1	EG1: 47 EG2: 31 CG: 34	Pain intensity (neck pain)	11-NRS	Pre-intervention Post-intervention	21
							Pain intensity (headache)	11-NRS		
							Disability associated with neck pain	11-NDI		
							ROM	VR device		
Cetin et al. (2022)	Turkey	Chronic neck pain (≥ 6 months)	NDI score of at least 20%	n = 34 EG = 17 CG = 17	EG: 40 ± 11.88 CG: 41.94 ± 10.76	EG: 29.5 CG: 35.3	ROM	ROM 3 device	Pre-intervention Post-intervention	21
							Joint position sense error	ROM 3 device		
							Pain intensity	VAS		
							PPT	Algometer		
							Muscle performance: strength	Hand dynamometer		
							Muscle performance: endurance	Pressure biofeedback device		
							Symptoms and functional limitations	ProFitMap-Neck		
							Anxiety and depression	HADS		
							Quality of life	SF-36		

SD Standard Deviation, *NDI* Neck Disability Index, *EG* experimental group, *CG* control group, *ROM* Range of Motion, *Vpeak* peak velocity, *Vmean* mean velocity, *TTP%* time to peak velocity percentage, *Sway* static head stability, *VAS* Visual Analogue Scale, *TSK* Tampa Scale of Kinesiophobia, *VR* Virtual Reality, *GPE* Global Perceived Effect, *11-NRS* Numerical Rating Scale, *SLS* Single Leg Standing, *NVP* Number of Velocity Peaks, *YBT* Y-balance Test, *CPM* Condition Pain Modulation, *TS* Temporal Summation, *PPT* Pain Pressure Treshold, *PCS* the Pain Catastrophizing Scale, *FABQ* the Fear-avoidance Beliefs Questionnaire, *PASS-20* 20-items version of the Pain Anxiety Symptoms Scale, *ProFitMap-Neck* Profile Fitness Mapping Questionnaire, *HADS* Hospital Anxiety-Depression Scale, *SF-36* Short Form Health Survey

Table 2 Characteristics of the interventions

References	Interventions	Session duration	Frequency	Program duration	Supervision	Adverse events
Bahat et al. (2015)	*EG: KT (laser + poster) + VRBR training* *VR System*: head-mounted display with a 3D motion tracker built in and Unity-pro software 3.5. *VRBR training*: the videogame consists of a virtual pilot flying the red airplane that was controlled by the patient's head motion and interacted with targets appearing from four directions. *Modules*: ROM, velocity and accuracy. *Training position*: sitting, standing and dynamic positions. *Time using VR*: 15–20 min. *Time using KT*: 10–15 min *CG: KT (laser + poster)* Laser pointer mounted on the participant's head and projected onto a poster for feedback. *Exercises*: active neck movements, quick head movements, static head positioning and smooth head movement. *Training position*: sitting, standing and dynamic positions *All*: unsupervised home KT (laser + poster) 30 min, at least 3 times a week. Continue until 3 months post-intervention	30 min	1 session per week (total: 4–6 sessions)	5 weeks	Supervised by a physiotherapist	Dizziness Nausea
Bahat et al. (2018)	*EG1: KT using VRBR at home* *VR system*: Oculus Rift DK1 and Unity-pro software 3.5. *VRBR training*: the videogame consists of a virtual pilot flying the red airplane that was controlled by the patient's head motion and interacted with targets appearing from four directions. *Modules*: ROM, velocity and accuracy. *Training position*: sitting, standing and dynamic positions. *Learning session*: 20 min. *Time using VR*: 20 min	20 min (5 min 4 times a day)	4 sessions per week	4 weeks	The physiotherapist contacted each participant weekly	Simulator sickness Headache
	EG2: KT (laser + poster) at home Laser pointer mounted on the participant's head and projected onto a poster for feedback. *Exercises*: active neck movements, quick head movements, static head positioning and smooth head movement. *Training position*: sitting, standing and dynamic positions					
	CG waited	–	–		–	–

Table 2 (continued)

References	Interventions	Session duration	Frequency	Program duration	Supervision	Adverse events
Rezaei et al. (2019)	*EG: VRBR training* *VR system*: monitor screen and Head Mouse Extreme®. *Game*: Cervigame®. *VRBR training*: the main visual component of the game is a rabbit attempting to reach carrots. This avatar is controlled by the patient's head movements. 50 stages divided into unidirectional and two-directional categories ordered from easy to hard. Score below 50%, the stage was repeated Warm-up: 5 min First 3 sessions (unidirectional stages); sessions 4–5 (both categories); last 3 sessions (two-directional stages) *Time using VR*: 1 min exercise/1 min rest. Reps: 8 *CG: conventional propioceptive training* *Warm-up*: 5 min. *Exercises*: eye-follow, gaze stability, eye-head coordination, position sense and movement sense training. *Time*: 1 min exercise/1 min rest. Reps: 8	21 min	2 sessions per week	4 weeks	Supervised by a physiotherapist	No adverse events
Tejera et al. (2020)	*EG: VRBR training* *VR system*: Vox Play glasses with head-mounted display clamping system and Smartphone (LG Q6). *VRBR treatment*: two VR mobile applications "Fulldive VR": first degree of difficulty. Only lateral flexion movements "VR Ocean Aquatium 3D": second degree of difficulty. Flexion, extension and rotation movements + sensory elements *Time using VR*: 3 series, 10 reps, 30 s rest *CG: exercises* *Exercises*: flexion, extension, rotation and tilt exercises. *Time*: 3 series, 10 reps, 30 s rest	–	2 sessions per week	4 weeks	Supervised by a physiotherapist	–

Table 2 (continued)

References	Interventions	Session duration	Frequency	Program duration	Supervision	Adverse events
Nusser et al. (2021)	*EG1: Neck-specific sensorimotor training with VR device + Standard rehabilitation programme* *VR system*: a modified VR system 3Space Fastrak system and a helmet with an integrated monitor. *VRBR training*: a globe was shown, moving in a virtual space on predetermined trajectories, on the monitor. The patient was asked to follow by moving the head the orbital pathways of the globe. The patient had to try to track the virtual globe as closely as possible with a white circle, whose position in the virtual scene corresponded to their head position. *Training position*: sitting. *Time using VR*: 20 min	20 min + –	2 sessions per week (total: 6 sessions)	3 weeks	Supervised by physiotherapists, sports scientists and scientific assistant	No adverse events (unpleasant sensations with the weight of the helmet were reported in EG1)
	EG2: General sensorimotor training + Standard rehabilitation programme *Skill exercises*: passing an obstacle course, dribbling, rope skipping, tossing balls through rings *Balance exercises*: standing with eyes closed, single-leg stance, slacklining *Small game forms*: juggling, curling, throwing and catching *Partner games*: badminton, table tennis	30 min + –	1–2 sessions per week (total: 4 sessions)		Supervised by physiotherapists and certified sports scientists	
	CG: Standard rehabilitation programme Combination of individual and group therapies. The programme comprised different forms of general and neck-specific exercise therapy (strengthening, mobilization, relaxation, medical training therapy, functional gymnastics, aqua therapy, physical therapy, and traditional "back school"). Patients also received special lectures from orthopaedists and psychologists about chronic pain	–	–			

Table 2 (continued)

References	Interventions	Session duration	Frequency	Program duration	Supervision	Adverse events
Cetin et al. (2022)	EG: VRBR training + motor control exercises *VR System*: Oculus Go VR glasses controlled by remote control. *VRBR training*: in the first session, the patients were trained to use the VR glasses and remote control. The patients were seated in a chair that allowed 360° movement and were asked to look in all directions during the VR application. Two VR applications were used: "Ocean Rift": allows watching sea animals that can be selected with the remote control "Gala 360": provides views from countries and cities all over the world *Time using VR*: 20 min (5 repetitions for each exercise). *Time motor control exercises*: 20 min *CG: motor control exercises* *Exercises*: 3-level treatment protocol developed by Jull et al. (2004): First level: craniocervical flexion exercises and cervical extension exercises Second level: elastic bands were used to increase the strength and endurance of the deep cervical flexors and extensors Third level: gain dynamic balance. The patient held an exercise ball against a wall with the front/back of the head Postures were maintained for 10 s in sitting and standing positions. Stretching was performed before each exercise session. *Time motor control exercises*: 40 min (10 repetitions for each exercise)	40 min	3 sessions per week	6 weeks	Supervised by a physiotherapist	No adverse events

EG Experimental Group, *KT* Kinematic Training, *VRBR* Virtual Reality Based Rehabilitation, *VR* Virtual Reality, *ROM* Range of Motion, *min* minutes, *CG* Control Group, *reps* repetitions, *s* seconds according to the following cut points as excellent (26–28), good (20–25), fair (15–19) and poor (≤ 14) (Silverman et al. 2012; Hooper et al. 2008).

2.6 Risk of bias

The risk of bias was assessed with the Revised Cochrane risk-of-bias tool (RoB-2) (Higgins et al. 2019). The tool is structured into five domains through which bias might be introduced into the result: bias arising from the randomisation process, due to deviations from the intended interventions, to missing outcome data, in the measurement of the outcome, and in the selection of the reported result. The different domains were scored as, "low risk of bias", "some concerns" or "high risk of bias".

Two independent reviewers (BBG and ALG) performed the assessment of methodological quality and risk of bias. If needed, discrepancies were resolved with a third reviewer (ITS).

2.7 Review registry

This systematic review is registered at The International Prospective Register of Systematic Reviews (PROSPERO) with number CRD42020222129. Available at: https://www.crd.york.ac.uk/prospero/display_record.php?RecordID=222129.

2.8 Statistical analysis

The statistical analysis was conducted using Review Manager (RevMan) 5.4. The analysis was performed for those outcomes repeated at least in two studies. Forest plots were used to visualize effect estimates and confidence intervals. Mean, standard deviation (SD) and sample size were extracted from included studies to estimate the overall effect. For continuous variables, results were expressed as mean difference (MD) with 95% confidence intervals (CI) when the variables were measured with the same instrument; and as standardized mean difference (SMD) when the instrument was different. The Visual Analogue Scale (VAS) was adjusted to a scale of 0–100 mm when it was expressed in centimetres. The 11-NRS also was adjusted to a scale of 0–100 points. We used inverse variance and random effects model (Deeks et al. 2022). A value of $p \leq 0.05$ was considered statistically significant. We evaluated the heterogeneity between studies with the I^2 test. Depending on the percentage obtained in I^2 test, heterogeneity could be classified as low ($I^2 < 25\%$), moderate ($I^2 = 25–75\%$), and high ($I^2 > 75\%$). We performed a subgroup analysis to explore possible causes of heterogeneity among study results. Subgroups were chosen based on VRBR interventions (VRBR applied alone or combined with other interventions), the type of no VRBR intervention, the type of VR (immersive, semi-immersive or non-immersive) and follow-up (short, mid or long-term follow-up). In addition, if 10 or more studies were available, we planned to use funnel plots with pseudo 95% confidence limits in order to inspect potential publication bias (Higgins et al. 2011). We emailed corresponding authors when data were unavailable to obtain clarifications.

3 Results

3.1 Search selection

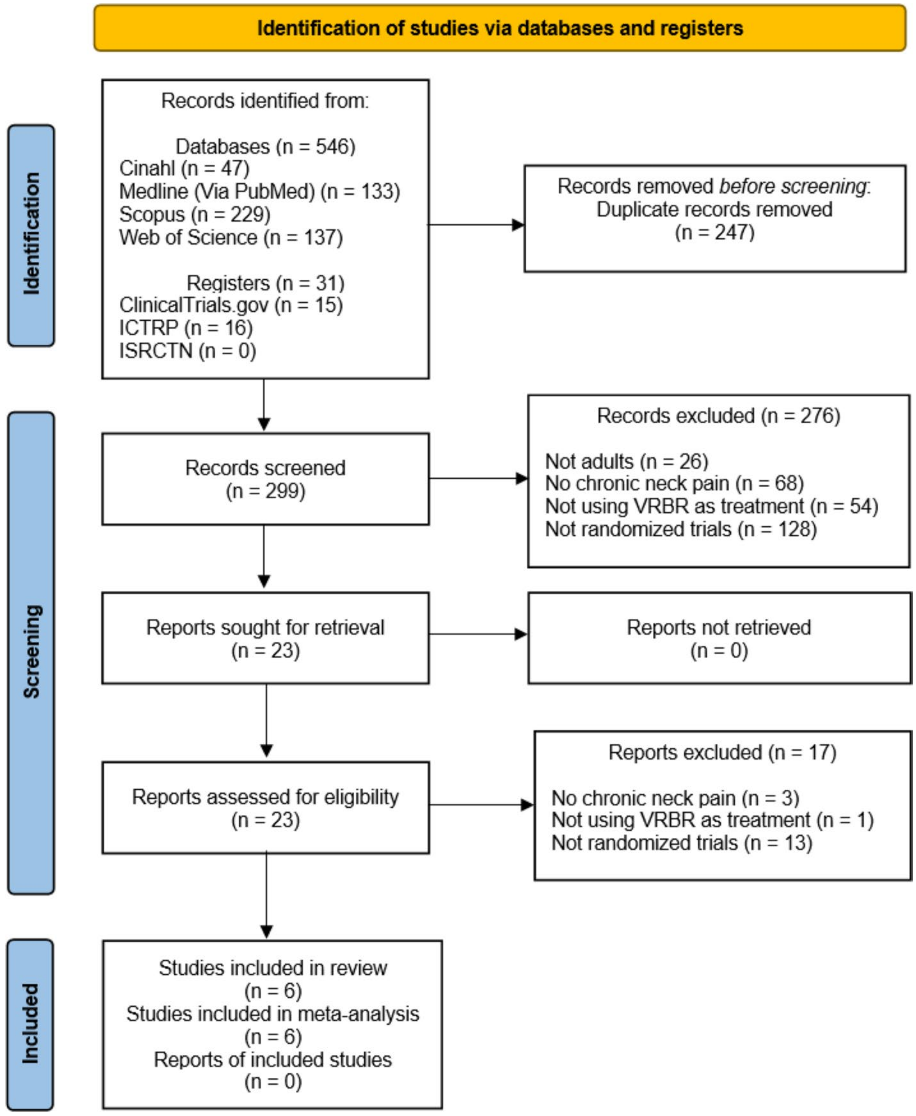
546 manuscripts were identified. After checking for duplicates, we obtained 299 potentially eligible records. Studies were screened by title and abstract and 23 studies remained. We evaluated the full text of them and 6 RCTs met the inclusion criteria. "Appendix 3" describes the excluded studies in the last screening with their reasons. Regarding ongoing RCTs, we found 31 potentially relevant registry entries. After screening, 10 ongoing RCTs were chosen. The study selection process is represented in the PRISMA flow diagram shown in Fig. 1. Ongoing RCTs are presented in "Appendix 4".

3.2 Characteristics of the studies

All included studies are RCTs and appear in tables chronologically from oldest to newest. The studies were published between 2015 and 2022 (Bahat et al. 2015, 2018; Rezaei et al. 2019; Tejera et al. 2020; Nusser et al. 2021; Cetin et al. 2022). The characteristics of the included studies are summarized in Table 1.

Two studies were carried out in Australia (Bahat et al. 2015, 2018), and one in Iran (Rezaei et al. 2019), Spain (Tejera et al. 2020), Germany (Nusser et al. 2021) and Turkey (Cetin et al. 2022). All participants suffered from chronic neck pain as we defined as an inclusion criterion on Sect. 2.3. Two studies (Rezaei et al. 2019; Tejera et al. 2020) specified that pain was nonspecific and one study that pain was non-traumatic (Nusser et al. 2021). Four studies (Bahat et al. 2015, 2018; Rezaei et al. 2019; Cetin et al. 2022) established severity criteria. 299 participants were studied. The sample sizes range from 32 to 90. The mean age of participants ranges from 26.26 to 53.1 years and the percentage of males ranges from 23 to 57.1%. All studies measured neck pain intensity (Bahat et al. 2015, 2018; Rezaei et al. 2019; Tejera et al. 2020; Nusser et al. 2021; Cetin et al. 2022) and five studies measured disability associated with neck pain (Bahat et al. 2015, 2018; Rezaei et al. 2019; Tejera et al. 2020; Nusser et al. 2021). In reference to neck pain intensity, the 11-points Numerical Rating Scale (11-NRS) (Nusser et al. 2021) and the VAS (0–100 mm or 0–10 cm) (Bahat et al. 2015, 2018;

Fig. 1 Flow diagram: database and clinical trial register search



Rezaei et al. 2019; Tejera et al. 2020; Cetin et al. 2022) were used as measurement tools. To assess disability, all studies used the Neck Pain Disability Index (NDI) (Bahat et al. 2015, 2018; Rezaei et al. 2019; Tejera et al. 2020; Nusser et al. 2021). Kinesiophobia was measured in two studies with the 17-items Tampa Scale of Kinesiophobia (17-TSK) (Bahat et al. 2015, 2018). Other study used the 11-items TSK (Tejera et al. 2020). Two studies assessed cervical kinematics [range of motion (ROM), peak velocity, mean velocity, time to peak velocity percentage (TTP%)] with the VRBR device used in each study (Bahat et al. 2015, 2018). Other three studies only measured ROM (Tejera et al. 2020; Nusser et al. 2021; Cetin et al. 2022). Global Perceived Effect (GPE) and patient satisfaction were measured in two studies using an 11-points scale (Bahat et al. 2015, 2018). Two studies assessed the pain pressure threshold (PPT) with an algometer (Tejera et al. 2020; Cetin et al. 2022).

The outcomes were assessed pre- and postintervention in all studies (Bahat et al. 2015, 2018; Rezaei et al. 2019; Tejera et al. 2020; Nusser et al. 2021; Cetin et al. 2022). Follow-up was carried out in four studies, two at three months (Bahat et al. 2015, 2018) and one at 5 weeks (Rezaei et al. 2019); another study included follow-up at one month and at three months (Tejera et al. 2020). Besides, one of these studies included a second recruitment after four weeks (Bahat et al. 2018).

3.3 Characteristics of the interventions

Table 2 describes the characteristics of the interventions of the included articles.

All interventions were VRBR training, in which head-mounted displays, VR glasses and specifically designed video games or software were used (Bahat et al. 2015, 2018; Rezaei et al. 2019; Tejera et al. 2020; Nusser et al.

2021; Cetin et al. 2022). The patient controlled (via head movements) a virtual avatar that had to achieve various objectives towards a therapeutic purpose (Bahat et al. 2015, 2018; Rezaei et al. 2019). In other cases, there was not a virtual avatar, but the movements of the head of the patient still interacted with the virtual environment producing changes (Tejera et al. 2020; Nusser et al. 2021; Cetin et al. 2022).

In Bahat et al. (2015) VRBR was combined with kinematic training (KT) (laser pointer + poster) and compared with KT alone. Cetin et al. (2022) performed a similar comparison with motor control exercises. Bahat et al. (2018) included three different groups, so VRBR was compared with KT and with a control group that did not receive intervention. Nusser et al. (2021) also included three groups and combined VRBR with a standard rehabilitation programme (SRP). They compared VRBR + SRP with a control group that performed SRP alone; and on the other hand, they compared VRBR + SRP with sensorimotor training + SRP. In the studies carried out by Rezaei et al. (2019) and Tejera et al. (2020) VRBR was compared with conventional proprioceptive training and cervical mobility exercises, respectively.

The time of use of VRBR during session ranges from 16 to 20 min and the session duration lasted from 20 to 40 min. The frequency of the sessions varied from 1 session (Bahat et al. 2015) to 4 sessions per week (Bahat et al. 2018). Program duration varied from 3 weeks (Nusser et al. 2021) to 6 weeks (Cetin et al. 2022). In four studies, a physiotherapist supervised the interventions (Bahat et al. 2015; Rezaei et al. 2019; Tejera et al. 2020; Cetin et al. 2022). In another one, a physiotherapist, a sports scientist or a scientific assistant supervised the interventions (Nusser et al. 2021). In Bahat et al. (2018), the physiotherapist contacted the patients weekly in a non-face-to-face way. In reference to side effects, two studies (Bahat et al. 2015, 2018) reported adverse effects related to VRBR. Other three studies (Rezaei et al. 2019; Nusser et al. 2021; Cetin et al. 2022) did not report side effects, but in one of them patients complained about unpleasant sensations with the weight of the helmet (Nusser et al. 2021). In one article, no information about this issue was included (Tejera et al. 2020).

3.4 Methodological quality

The methodological quality was assessed with the Downs and Black quality assessment method (Downs et al. 1998). The score of each item is shown in "Appendix 5". Five studies (Bahat et al. 2015; Rezaei et al. 2019; Tejera et al. 2020; Nusser et al. 2021; Cetin et al. 2022) were evaluated as good (20–25) and one (Bahat et al. 2018) was evaluated as fair (19–15).

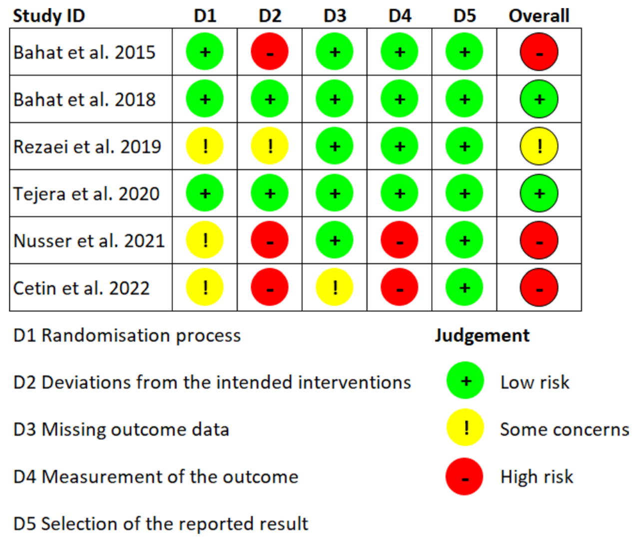


Fig. 2 Risk of bias summary

3.5 Risk of bias

We used RoB-2 to assess the risk of bias of the included studies (Higgins et al. 2019). Figures 2 and 3 present the summary and the graph of the risk of bias assessment, respectively. The ROB-2 overall score reported that three studies were assessed as "high risk of bias" (Bahat et al. 2015; Nusser et al. 2021; Cetin et al. 2022) and two studies were assessed as "low risk of bias" (Bahat et al. 2018; Tejera et al. 2020). One was assessed as "some concerns" (Rezaei et al. 2019).

3.6 Effects of VRBR versus No VRBR in chronic neck pain

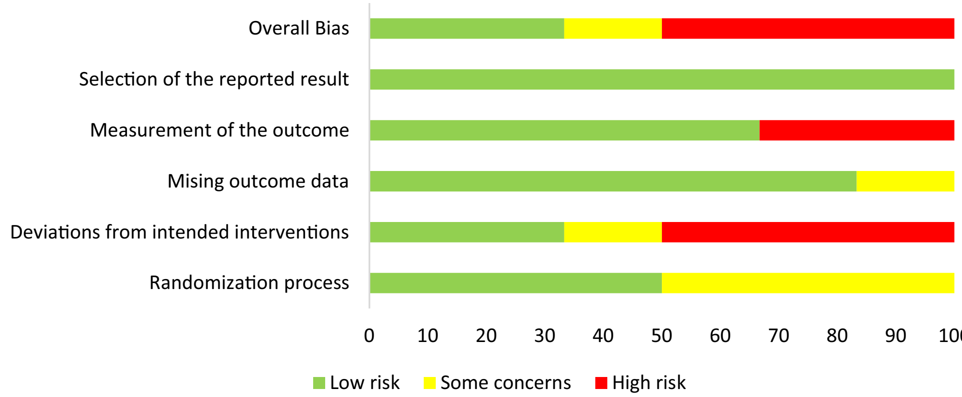
To perform the meta-analysis, we considered all outcomes repeated in two or more articles. We analysed the effects of VRBR versus no VRBR for six outcomes. The six included articles in the systematic review were included in the meta-analysis.

VRBR was compared with interventions without VRBR. We found two types of intervention without VRBR among studies, rehabilitation and control intervention. In order to clarify meta-analysis and draw solid conclusions it was divided in two parts: effects of VRBR vs rehabilitation in chronic neck pain; and effects of VRBR vs control intervention in chronic neck pain.

3.6.1 Effects of VRBR versus rehabilitation in chronic neck pain

All of the studies evaluated pain intensity (Bahat et al. 2015, 2018; Rezaei et al. 2019; Tejera et al. 2020; Nusser

Fig. 3 Risk of bias graph



et al. 2021; Cetin et al. 2022) and five evaluated disability (Bahat et al. 2015, 2018; Rezaei et al. 2019; Tejera et al. 2020; Nusser et al. 2021). For kinesiophobia, three articles were included (Bahat et al. 2015, 2018; Tejera et al. 2020). For cervical kinematics, two articles were included (Bahat et al. 2015, 2018) for all parameters and other two only were considered for ROM (Nusser et al. 2021; Cetin et al. 2022). Tejera et al. (2020) was not included in the meta-analysis for ROM because data was not comparable. Two articles were included for global perceived effect and patient satisfaction (Bahat et al. 2015, 2018).

In order to explore the heterogeneity a subgroup analysis was performed:

First, we conducted a subgroup analysis based on VRBR interventions in order to figure out if VR applied alone obtained different effects compared with VR combined with a physiotherapy treatment.

Second, a subgroup analysis based on no VRBR interventions was performed. In this case, no VRBR interventions were rehabilitation interventions. These subgroups could only be performed for pain intensity and disability. We could not conduct a subgroup analysis based on the type of VR since all included studies used immersive VR, except Rezaei et al. (2019). It was also not possible to perform subgroups based on follow-up because the studies only included short-term follow-up (< 3 months).

Therefore, we analysed the effects of VRBR versus rehabilitation at short-term follow-up for pain intensity, disability, kinesiophobia, cervical kinematics and global perceived effect. We included four articles in pain intensity and disability analysis (Bahat et al. 2015, 2018; Rezaei et al. 2019; Tejera et al. 2020) and three studies in kinesiophobia analysis (Bahat et al. 2015, 2018; Tejera et al. 2020). We included two studies in cervical kinematic analysis and global perceived effect analysis at short-term follow-up (Bahat et al. 2015, 2018). We did not carry out meta-analysis for patient satisfaction at short-term follow-up because data was missing in one article (Bahat et al. 2015).

For cervical kinematics, subgroups were based on the different parameters and for global perceived effect and patient satisfaction, subgroup analysis was not performed. The VAS to evaluate pain intensity was adjusted to a scale of 0–100 mm when it was expressed in centimetres. The 11-NRS also was adjusted to a scale of 0–100 points.

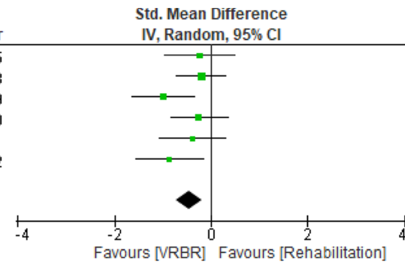
3.6.1.1 Pain intensity Six studies evaluated pain intensity; five studies used VAS (0–100 mm) (Bahat et al. 2015, 2018; Rezaei et al. 2019; Tejera et al. 2020; Cetin et al. 2022) and other study used 11-NRS (Nusser et al. 2021). In Fig. 4a, we observed that VRBR turned out to be statistically more effective than rehabilitation for pain intensity (SMD = −0.46; 95% CI = −0.74, −0.19; $p = 0.001$). According to the I^2 statistic, 12% of variation across studies was due to heterogeneity ($p = 0.34$).

Regarding subgroup analysis based on VRBR interventions, no significant differences were found between VRBR and rehabilitation when VRBR was applied alone (SMD = −0.46; 95% CI = −0.93, 0.02; $p = 0.06$). According to the I^2 statistic, 50% of variation across studies was due to heterogeneity ($p = 0.14$). However, the results showed significant differences in favour of VRBR when it was combined with other intervention versus rehabilitation (SMD = −0.50; 95% CI = −0.91, −0.09; $p = 0.02$). Heterogeneity was not significant ($I^2 = 0\%$; $p = 0.44$) (Fig. 4b). In subgroup analysis based on rehabilitation interventions (Fig. 4c), there were no significant differences between VRBR and KT (SMD = −0.22; 95% CI = −0.63, 0.20; $p = 0.31$). Heterogeneity was not significant ($I^2 = 0\%$; $p = 0.95$). However, we observed significant differences in favour of VRBR when it was compared with therapeutic exercise (SMD = −0.61; 95% CI = −0.97, −0.25; $p = 0.0009$). According to the I^2 statistic, 17% of variation across studies was due to heterogeneity ($p = 0.31$).

Four studies evaluated pain intensity at short-term follow-up using VAS (0–100 mm) (Bahat et al. 2015, 2018; Rezaei et al. 2019; Tejera et al. 2020). As shown in Fig. 4d, no significant differences (MD = −6.12; 95% CI = −12.74, 0.49;

Study or Subgroup	VRBR Mean	VRBR SD	VRBR Total	Rehabilitation Mean	Rehabilitation SD	Rehabilitation Total	Weight	Std. Mean Difference IV, Random, 95% CI	Year
Bahat 2015	22.1	24.1	16	27.72	21.9	14	13.2%	-0.24 [-0.96, 0.48]	2015
Bahat 2018	31.1	23.6	30	35.97	22.9	30	24.2%	-0.21 [-0.71, 0.30]	2018
Rezaei 2019	10.75	8.43	21	19.63	9.15	21	16.1%	-0.99 [-1.63, -0.35]	2019
Tejera 2020	26.7	19.1	22	31.1	14.7	22	18.6%	-0.25 [-0.85, 0.34]	2020
Nusser 2021	22	12	17	29	22	16	14.3%	-0.39 [-1.08, 0.30]	2021
Cetin 2022	20.7	12	17	35.4	20.2	17	13.6%	-0.86 [-1.57, -0.16]	2022
Total (95% CI)			**123**			**120**	**100.0%**	**-0.46 [-0.74, -0.19]**	

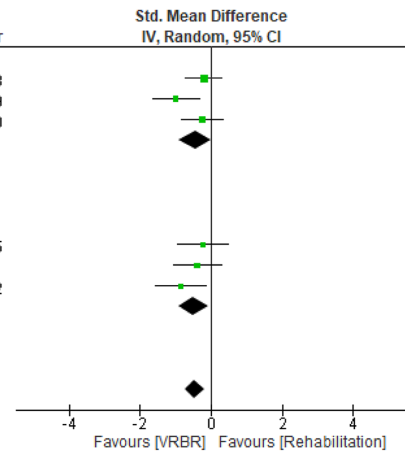
Heterogeneity: $Tau^2 = 0.01$; $Chi^2 = 5.69$, df = 5 (P = 0.34); $I^2 = 12\%$
Test for overall effect: Z = 3.28 (P = 0.001)



(a)

Study or Subgroup	VRBR Mean	VRBR SD	VRBR Total	Rehabilitation Mean	Rehabilitation SD	Rehabilitation Total	Weight	Std. Mean Difference IV, Random, 95% CI	Year
1.2.1 VRBR applied alone									
Bahat 2018	31.1	23.6	30	35.97	22.9	30	24.2%	-0.21 [-0.71, 0.30]	2018
Rezaei 2019	10.75	8.43	21	19.63	9.15	21	16.1%	-0.99 [-1.63, -0.35]	2019
Tejera 2020	26.7	19.1	22	31.1	14.7	22	18.6%	-0.25 [-0.85, 0.34]	2020
Subtotal (95% CI)			**73**			**73**	**58.9%**	**-0.46 [-0.93, 0.02]**	
Heterogeneity: $Tau^2 = 0.09$; $Chi^2 = 3.99$, df = 2 (P = 0.14); $I^2 = 50\%$									
Test for overall effect: Z = 1.89 (P = 0.06)									
1.2.2 VRBR combined with other intervention									
Bahat 2015	22.1	24.1	16	27.72	21.9	14	13.2%	-0.24 [-0.96, 0.48]	2015
Nusser 2021	22	12	17	29	22	16	14.3%	-0.39 [-1.08, 0.30]	2021
Cetin 2022	20.7	12	17	35.4	20.2	17	13.6%	-0.86 [-1.57, -0.16]	2022
Subtotal (95% CI)			**50**			**47**	**41.1%**	**-0.50 [-0.91, -0.09]**	
Heterogeneity: $Tau^2 = 0.00$; $Chi^2 = 1.63$, df = 2 (P = 0.44); $I^2 = 0\%$									
Test for overall effect: Z = 2.40 (P = 0.02)									
Total (95% CI)			**123**			**120**	**100.0%**	**-0.46 [-0.74, -0.19]**	

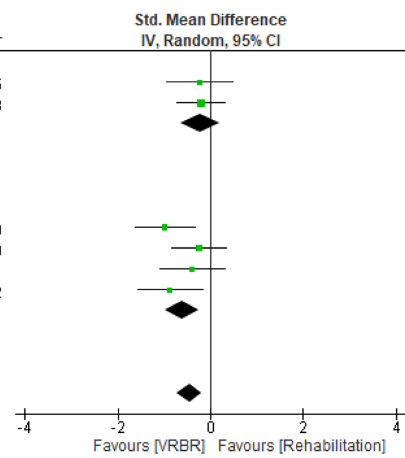
Heterogeneity: $Tau^2 = 0.01$; $Chi^2 = 5.69$, df = 5 (P = 0.34); $I^2 = 12\%$
Test for overall effect: Z = 3.28 (P = 0.001)
Test for subgroup differences: $Chi^2 = 0.02$, df = 1 (P = 0.89), $I^2 = 0\%$



(b)

Study or Subgroup	VRBR Mean	VRBR SD	VRBR Total	Rehabilitation Mean	Rehabilitation SD	Rehabilitation Total	Weight	Std. Mean Difference IV, Random, 95% CI	Year
1.3.1 Kinematic Training									
Bahat 2015	22.1	24.1	16	27.72	21.9	14	13.2%	-0.24 [-0.96, 0.48]	2015
Bahat 2018	31.1	23.6	30	35.97	22.9	30	24.2%	-0.21 [-0.71, 0.30]	2018
Subtotal (95% CI)			**46**			**44**	**37.4%**	**-0.22 [-0.63, 0.20]**	
Heterogeneity: $Tau^2 = 0.00$; $Chi^2 = 0.00$, df = 1 (P = 0.95); $I^2 = 0\%$									
Test for overall effect: Z = 1.02 (P = 0.31)									
1.3.2 Therapeutic Exercise									
Rezaei 2019	10.75	8.43	21	19.63	9.15	21	16.1%	-0.99 [-1.63, -0.35]	2019
Tejera 2020	26.7	19.1	22	31.1	14.7	22	18.6%	-0.25 [-0.85, 0.34]	2020
Nusser 2021	22	12	17	29	22	16	14.3%	-0.39 [-1.08, 0.30]	2021
Cetin 2022	20.7	12	17	35.4	20.2	17	13.6%	-0.86 [-1.57, -0.16]	2022
Subtotal (95% CI)			**77**			**76**	**62.6%**	**-0.61 [-0.97, -0.25]**	
Heterogeneity: $Tau^2 = 0.02$; $Chi^2 = 3.61$, df = 3 (P = 0.31); $I^2 = 17\%$									
Test for overall effect: Z = 3.31 (P = 0.0009)									
Total (95% CI)			**123**			**120**	**100.0%**	**-0.46 [-0.74, -0.19]**	

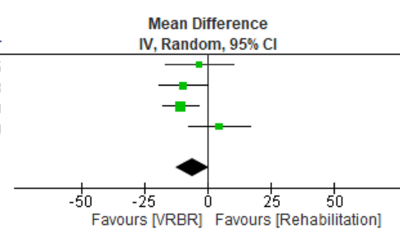
Heterogeneity: $Tau^2 = 0.01$; $Chi^2 = 5.69$, df = 5 (P = 0.34); $I^2 = 12\%$
Test for overall effect: Z = 3.28 (P = 0.001)
Test for subgroup differences: $Chi^2 = 1.95$, df = 1 (P = 0.16), $I^2 = 48.8\%$



(c)

Study or Subgroup	VRBR Mean	VRBR SD	VRBR Total	Rehabilitation Mean	Rehabilitation SD	Rehabilitation Total	Weight	Mean Difference IV, Random, 95% CI	Year
Bahat 2015	26.95	16.5	14	30.33	18.5	12	17.1%	-3.38 [-16.95, 10.19]	2015
Bahat 2018	25.43	23.1	48	35.26	24.1	44	26.5%	-9.83 [-19.50, -0.16]	2018
Rezaei 2019	9.57	11.03	21	20.17	11.97	21	36.3%	-10.60 [-17.56, -3.64]	2019
Tejera 2020	21.7	19.9	22	17.2	20.9	22	20.1%	4.50 [-7.56, 16.56]	2020
Total (95% CI)			**105**			**99**	**100.0%**	**-6.12 [-12.74, 0.49]**	

Heterogeneity: $Tau^2 = 18.71$; $Chi^2 = 5.12$, df = 3 (P = 0.16); $I^2 = 41\%$
Test for overall effect: Z = 1.82 (P = 0.07)



(d)

◂**Fig. 4** Forest plot summarizing SMD or MD and 95% CI for the effects of VRBR versus rehabilitation in chronic neck pain for pain intensity (**a**), subgroup analysis (**b**, **c**) and pain intensity at short-term follow-up (**d**). *VRBR* Virtual Reality Based Rehabilitation

$p=0.07$) were found between VRBR and rehabilitation in pain intensity at short term follow-up. According to the I^2 statistic, 41% of variation across studies was due to heterogeneity ($p=0.16$).

3.6.1.2 Disability Five studies evaluated disability using NDI (Bahat et al. 2015, 2018; Rezaei et al. 2019; Tejera et al. 2020; Nusser et al. 2021). In Fig. 5a, we observed that VRBR turned out to be statistically more effective than rehabilitation for disability (MD = −2.84; 95% CI = −4.23, −1.45; $p<0.0001$). Heterogeneity was not significant ($I^2=0\%$; $p=0.59$).

Regarding subgroup analysis based on VRBR interventions, we observed significant differences in favour of VRBR versus rehabilitation when VRBR was applied alone (MD = −2.79; 95% CI = −4.67, −0.91; $p=0.004$). According to the I^2 statistic, 16% of variation across studies was due to heterogeneity ($p=0.30$). However, no significant differences were found between VRBR and rehabilitation when VRBR was combined with other intervention (MD = −1.78; 95% CI = −5.67, 2.11; $p=0.37$). Heterogeneity was not significant ($I^2=0\%$; $p=0.77$) (Fig. 5b). In subgroup analysis based on rehabilitation interventions (Fig. 5c), no significant differences were found between VRBR and KT (MD = −1.88; 95% CI = −6.46, 2.70; $p=0.42$). Heterogeneity was not significant ($I^2=0\%$; $p=0.68$). However, the results showed significant differences in favour of VRBR when it was compared with therapeutic exercise (MD = −2.72; 95% CI = −4.54, −0.89; $p=0.004$). According to the I^2 statistic, 18% of variation across studies was due to heterogeneity ($p=0.30$).

Four studies evaluated disability at short-term follow-up using NDI (Bahat et al. 2015, 2018; Rezaei et al. 2019; Tejera et al. 2020). For disability at short-term follow-up (Fig. 5b), we obtained significant differences in favour of VRBR when we compared with rehabilitation (MD = −3.52; 95% CI = −5.85, −1.20; $p=0.003$). According to the I^2 statistic, 26% of variation across studies was due to heterogeneity ($p=0.26$).

3.6.1.3 Kinesiophobia Three studies evaluated kinesiophobia; two studies used 17-TSK (Bahat et al. 2015, 2018) and other study used 11-items TSK (Tejera et al. 2020). For kinesiophobia (Fig. 6a), no significant differences (SMD = −0.18; 95% CI = −0.52, 0.17; $p=0.31$) were found between VRBR and rehabilitation. Heterogeneity was not significant ($I^2=0\%$; $p=0.96$).

Three studies evaluated kinesiophobia at short-term follow-up; two studies used 17-TSK (Bahat et al. 2015, 2018) and other study used 11-items TSK (Tejera et al. 2020). For kinesiophobia at short term follow-up (Fig. 6b), there were no significant differences between VRBR and rehabilitation (SMD = −0.29; 95% CI = −0.73, 0.15; $p=0.19$). According to the I^2 statistic, 42% of variation across studies was due to heterogeneity ($p=0.18$).

3.6.1.4 Cervical kinematics Four studies evaluated ROM; two used a VR device (Bahat et al. 2015, 2018) and two used a ROM device (Nusser et al. 2021; Cetin et al. 2022). The rest of cervical kinematic parameters were evaluated in two studies with a different VR device (Bahat et al. 2015, 2018). Regarding cervical kinematics parameters (Fig. 7), no significant differences were found for ROM (SMD = 0.18; 95% CI = −0.03, 0.38; $p=0.09$), peak velocity (SMD = 0.03; 95% CI = −0.18, 0.24; $p=0.76$), mean velocity (SMD = 0.03; 95% CI = −0.18, 0.24; $p=0.76$) or TTP% (SMD = 0.05; 95% CI = −0.31, 0.41; $p=0.78$).

Two studies evaluated cervical kinematic parameters at short-term follow-up with a different VR device (Bahat et al. 2015, 2018). Regarding cervical kinematics parameters at short-term follow-up (Fig. 8), no significant differences were found for peak velocity (SMD = 0.03; 95% CI = −0.20, 0.26; $p=0.78$), mean velocity (SMD = −0.03; 95% CI = −0.30, 0.24; $p=0.82$) or TTP% (SMD = −0.17; 95% CI = −0.51, 0.16; $p=0.31$). However, there were statistically significant differences in favour of rehabilitation for ROM (SMD = −0.42; 95% CI = −0.65, −0.19; $p=0.0003$). In addition, subgroup analysis showed significant differences in favour of rehabilitation for ROM flexion (SMD = −0.67; 95% CI = −1.08, −0.25; $p=0.002$) and ROM right rotation (SMD = −0.64; 95% CI = −1.02, −0.25; $p=0.001$).

3.6.1.5 Global perceived effect Two studies evaluated global perceived effect with 11-points scale (Bahat et al. 2015, 2018). The results in Fig. 9a showed significant differences (MD = 0.49; 95% CI = 0.25, 0.72; $p<0.0001$) in favour of VRBR in global perceived effect when we compared with rehabilitation. Heterogeneity was not significant ($I^2=0\%$; $p=0.86$). However, no significant differences (MD = 1.22; 95% CI = −0.40, 2.83; $p=0.14$) were found at short-term follow-up (Fig. 9b). Heterogeneity between studies was high ($I^2=93\%$; $p=0.0002$).

3.6.1.6 Patient satisfaction Two studies evaluated patient satisfaction with 11-points scale (Bahat et al. 2015, 2018). In Fig. 10, we observed that significant differences (MD = 0.62; 95% CI = 0.38, 0.86; $p<0.00001$) in favour of VRBR were found in patient satisfaction when we compared with rehabilitation. Heterogeneity was not significant ($I^2=0\%$; $p=0.57$).

3.6.2 Effects of VRBR versus control intervention in chronic neck pain

Two studies included a control group (Bahat et al. 2018; Nusser et al. 2021). We could not perform subgroup analysis due to the lack of studies that analysed this comparison. We analysed the effects of VRBR versus control group for pain intensity, disability and ROM.

3.6.2.1 Pain intensity Two studies evaluated pain intensity; one used VAS (0–100 mm) (Bahat et al. 2018) and the other one used 11-NRS (Nusser et al. 2021). In Fig. 11, no significant differences (SMD=-0.38; 95% CI = −0.79, 0.02; $p=0.06$) were found between VRBR and control intervention for pain intensity. Heterogeneity was not significant ($I^2=0\%$; $p=0.89$).

3.6.2.2 Disability Two studies evaluated disability with NDI (Bahat et al. 2018; Nusser et al. 2021). In Fig. 12, no significant differences (MD = −1.52; 95% CI = −5.49, 2.45; $p=0.45$) were found between VRBR and control intervention for disability. Heterogeneity was not significant ($I^2=0\%$; $p=0.57$).

3.6.2.3 Cervical kinematics Two studies evaluated ROM; one used a VR device (Bahat et al. 2018) and the other one used a ROM device (Nusser et al. 2021). In Fig. 13, no significant differences (SMD = −0.13; 95% CI = −0.38, 0.12; $p=0.33$) were found between VRBR and control intervention for ROM. According to the I^2 statistic, 33% of variation across studies was due to heterogeneity ($p=0.17$). Subgroup analysis did not show significant differences.

3.7 Interpretation of the results

Regarding the magnitude of effects and the interpretation of the effects of VRBR versus rehabilitation postintervention we can consider that:

Pain intensity improved around 1,7% in the VRBR group compared to the rehabilitation group considering a relative error of 1,1% (obtained from 95% CI).

Disability improved around 22% in the VRBR group compared to the rehabilitation group considering a relative error of 11% (obtained from 95% CI).

Global perceived effect improved around 25% in the VRBR group compared to the rehabilitation group considering a relative error of 12% (obtained from 95% CI).

Patient satisfaction improved around 22% in the VRBR group compared to the rehabilitation group considering a relative error of 8% (obtained from 95% CI).

Only the significant results of the outcomes have been detailed in this summary.

Fig. 5 Forest plot summarizing MD and 95% CI for the effects of VRBR versus rehabilitation in chronic neck pain for disability (**a**), subgroup analysis (**b**, **c**) and disability at short-term follow-up (**d**). VRBR: Virtual Reality Based Rehabilitation ▸

3.8 Publication bias

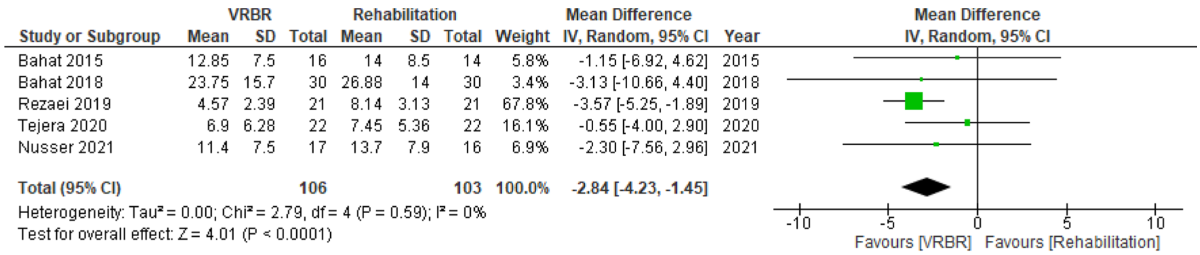
Finally, publication bias assessment was not performed because it is not recommended for fewer than 10 articles (Higgins et al. 2011) and we were only able to include 6 articles.

4 Discussion

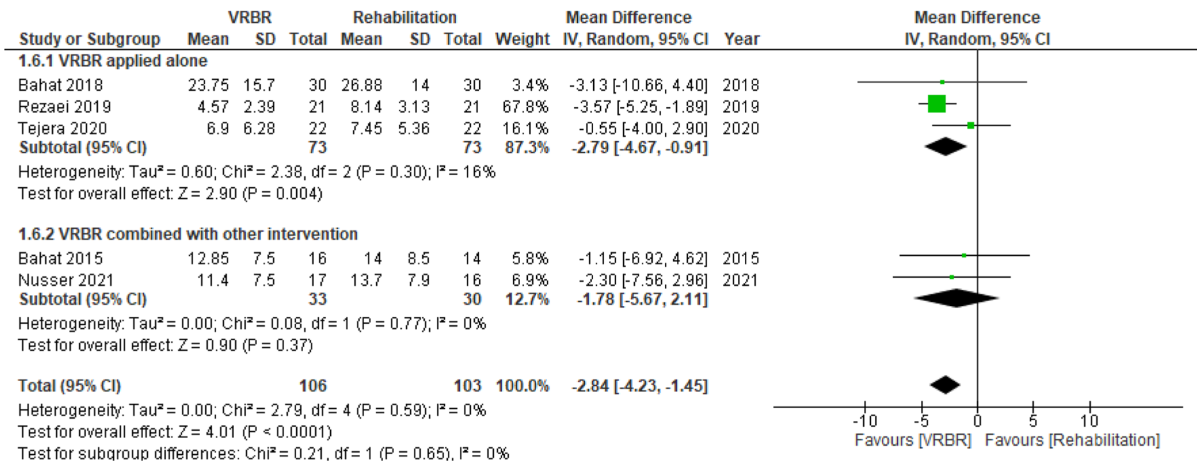
The purpose of this meta-analysis was to analyse the effectiveness of VRBR in adults with chronic neck pain. Significant differences in favour of VRBR were found for pain intensity, disability, global perceived effect and patient satisfaction when it was compared with rehabilitation. No significant differences were found for kinesiophobia and cervical kinematics. At short-term follow-up we only found significant differences in favour of VRBR for disability. However, the results showed significant differences in favour of rehabilitation for ROM at short-term follow-up. When VRBR was compared with a control intervention no significant differences were found. It should be noted that only two studies were included in this meta-analysis.

Meta-analysis showed a significant improvement in favour of VRBR in *pain intensity* and *disability*. We observed that VRBR turned out to be statistically more effective than rehabilitation in both outcomes. In addition, significant differences were shown in favour of VRBR when compared with therapeutic exercise. No significant differences were observed when compared with KT. However, it should be considered that in this subgroup only two studies were included and in one study (Bahat et al. 2015) VRBR group also used KT and had a limited time of VR training. It should be noted that some studies had a small sample size (Bahat et al. 2015; Nusser et al. 2021), and a high dropout rate (Bahat et al. 2015; Cetin 2022). Regarding VRBR interventions, we observed conflicting results when VRBR was applied alone or combined with other intervention. VRBR combined with other intervention was superior to rehabilitation for pain intensity but not for disability. On the other hand, VRBR applied alone was superior to rehabilitation for disability but not for pain intensity. In addition, interventions combined with VRBR were heterogeneous.

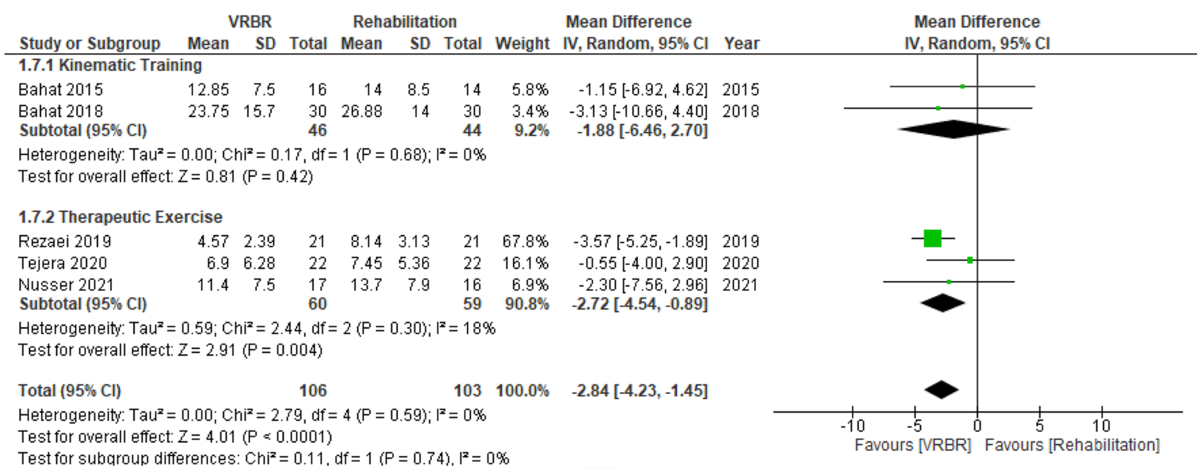
For pain intensity, no significant differences were found at *short-term follow-up*. However, we found significant differences in favour of VRBR for disability. Some limitations shall be considered. For instance, Bahat et al. (2015) included the same home exercise programme for both groups


VRBR | Rehabilitation | Mean Difference | Mean Difference
Study or Subgroup | Mean | SD | Total | Mean | SD | Total | Weight | IV, Random, 95% CI | Year | IV, Random, 95% CI
Bahat 2015 | 12.85 | 7.5 | 16 | 14 | 8.5 | 14 | 5.8% | -1.15 [-6.92, 4.62] | 2015
Bahat 2018 | 23.75 | 15.7 | 30 | 26.88 | 14 | 30 | 3.4% | -3.13 [-10.66, 4.40] | 2018
Rezaei 2019 | 4.57 | 2.39 | 21 | 8.14 | 3.13 | 21 | 67.8% | -3.57 [-5.25, -1.89] | 2019
Tejera 2020 | 6.9 | 6.28 | 22 | 7.45 | 5.36 | 22 | 16.1% | -0.55 [-4.00, 2.90] | 2020
Nusser 2021 | 11.4 | 7.5 | 17 | 13.7 | 7.9 | 16 | 6.9% | -2.30 [-7.56, 2.96] | 2021
Total (95% CI) | 106 | 103 | 100.0% | -2.84 [-4.23, -1.45]
Heterogeneity: Tau² = 0.00; Chi² = 2.79, df = 4 (P = 0.59); I² = 0%
Test for overall effect: Z = 4.01 (P < 0.0001)
-10 -5 0 5 10
Favours [VRBR] Favours [Rehabilitation]

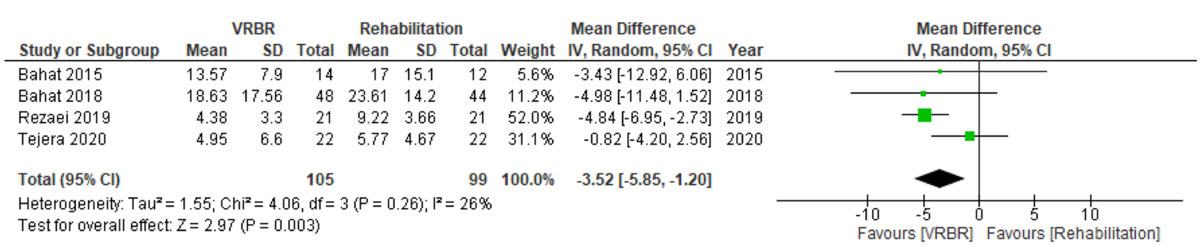
(a)


VRBR | Rehabilitation | Mean Difference | Mean Difference
Study or Subgroup | Mean | SD | Total | Mean | SD | Total | Weight | IV, Random, 95% CI | Year | IV, Random, 95% CI
1.6.1 VRBR applied alone
Bahat 2018 | 23.75 | 15.7 | 30 | 26.88 | 14 | 30 | 3.4% | -3.13 [-10.66, 4.40] | 2018
Rezaei 2019 | 4.57 | 2.39 | 21 | 8.14 | 3.13 | 21 | 67.8% | -3.57 [-5.25, -1.89] | 2019
Tejera 2020 | 6.9 | 6.28 | 22 | 7.45 | 5.36 | 22 | 16.1% | -0.55 [-4.00, 2.90] | 2020
Subtotal (95% CI) | 73 | 73 | 87.3% | -2.79 [-4.67, -0.91]
Heterogeneity: Tau² = 0.60; Chi² = 2.38, df = 2 (P = 0.30); I² = 16%
Test for overall effect: Z = 2.90 (P = 0.004)
1.6.2 VRBR combined with other intervention
Bahat 2015 | 12.85 | 7.5 | 16 | 14 | 8.5 | 14 | 5.8% | -1.15 [-6.92, 4.62] | 2015
Nusser 2021 | 11.4 | 7.5 | 17 | 13.7 | 7.9 | 16 | 6.9% | -2.30 [-7.56, 2.96] | 2021
Subtotal (95% CI) | 33 | 30 | 12.7% | -1.78 [-5.67, 2.11]
Heterogeneity: Tau² = 0.00; Chi² = 0.08, df = 1 (P = 0.77); I² = 0%
Test for overall effect: Z = 0.90 (P = 0.37)
Total (95% CI) | 106 | 103 | 100.0% | -2.84 [-4.23, -1.45]
Heterogeneity: Tau² = 0.00; Chi² = 2.79, df = 4 (P = 0.59); I² = 0%
Test for overall effect: Z = 4.01 (P < 0.0001)
Test for subgroup differences: Chi² = 0.21, df = 1 (P = 0.65), I² = 0%
-10 -5 0 5 10
Favours [VRBR] Favours [Rehabilitation]

(b)


VRBR | Rehabilitation | Mean Difference | Mean Difference
Study or Subgroup | Mean | SD | Total | Mean | SD | Total | Weight | IV, Random, 95% CI | Year | IV, Random, 95% CI
1.7.1 Kinematic Training
Bahat 2015 | 12.85 | 7.5 | 16 | 14 | 8.5 | 14 | 5.8% | -1.15 [-6.92, 4.62] | 2015
Bahat 2018 | 23.75 | 15.7 | 30 | 26.88 | 14 | 30 | 3.4% | -3.13 [-10.66, 4.40] | 2018
Subtotal (95% CI) | 46 | 44 | 9.2% | -1.88 [-6.46, 2.70]
Heterogeneity: Tau² = 0.00; Chi² = 0.17, df = 1 (P = 0.68); I² = 0%
Test for overall effect: Z = 0.81 (P = 0.42)
1.7.2 Therapeutic Exercise
Rezaei 2019 | 4.57 | 2.39 | 21 | 8.14 | 3.13 | 21 | 67.8% | -3.57 [-5.25, -1.89] | 2019
Tejera 2020 | 6.9 | 6.28 | 22 | 7.45 | 5.36 | 22 | 16.1% | -0.55 [-4.00, 2.90] | 2020
Nusser 2021 | 11.4 | 7.5 | 17 | 13.7 | 7.9 | 16 | 6.9% | -2.30 [-7.56, 2.96] | 2021
Subtotal (95% CI) | 60 | 59 | 90.8% | -2.72 [-4.54, -0.89]
Heterogeneity: Tau² = 0.59; Chi² = 2.44, df = 2 (P = 0.30); I² = 18%
Test for overall effect: Z = 2.91 (P = 0.004)
Total (95% CI) | 106 | 103 | 100.0% | -2.84 [-4.23, -1.45]
Heterogeneity: Tau² = 0.00; Chi² = 2.79, df = 4 (P = 0.59); I² = 0%
Test for overall effect: Z = 4.01 (P < 0.0001)
Test for subgroup differences: Chi² = 0.11, df = 1 (P = 0.74), I² = 0%
-10 -5 0 5 10
Favours [VRBR] Favours [Rehabilitation]

(c)


VRBR | Rehabilitation | Mean Difference | Mean Difference
Study or Subgroup | Mean | SD | Total | Mean | SD | Total | Weight | IV, Random, 95% CI | Year | IV, Random, 95% CI
Bahat 2015 | 13.57 | 7.9 | 14 | 17 | 15.1 | 12 | 5.6% | -3.43 [-12.92, 6.06] | 2015
Bahat 2018 | 18.63 | 17.56 | 48 | 23.61 | 14.2 | 44 | 11.2% | -4.98 [-11.48, 1.52] | 2018
Rezaei 2019 | 4.38 | 3.3 | 21 | 9.22 | 3.66 | 21 | 52.0% | -4.84 [-6.95, -2.73] | 2019
Tejera 2020 | 4.95 | 6.6 | 22 | 5.77 | 4.67 | 22 | 31.1% | -0.82 [-4.20, 2.56] | 2020
Total (95% CI) | 105 | 99 | 100.0% | -3.52 [-5.85, -1.20]
Heterogeneity: Tau² = 1.55; Chi² = 4.06, df = 3 (P = 0.26); I² = 26%
Test for overall effect: Z = 2.97 (P = 0.003)
-10 -5 0 5 10
Favours [VRBR] Favours [Rehabilitation]

(d)

in the postintervention period. This could explain the lack of significant differences found at short-term follow-up for pain intensity. Significant differences were not found between VRBR and rehabilitation for *kinesiophobia*. It was not found in the short-term follow-up, either. It should be noted that only three articles were included in each meta-analysis. However, a recent systematic review (Wang et al. 2022) concluded that VRBR technology has the potential to reduce kinesiophobia. They also reported that non-immersive VRBR and VRBR combined with exercise were effective. In our meta-analysis, none of the articles used non-immersive VR and only one (Bahat et al. 2015) combined VR with other intervention (KT).

In general, no significant differences were found in favour of VRBR for *cervical kinematics parameters*. It was not found in the short-term follow-up, either. Even considering that the included studies (Bahat et al. 2015, 2018) used the same VR system to assess and treat the patients (which might have been an advantage for the VRBR group), significant differences were found in favour of rehabilitation for ROM at short-term follow-up. The results could be explained because only two studies were included.

Only two articles were included in *global perceived effect* and *patient satisfaction* meta-analysis (Bahat et al. 2015, 2018). The results showed significant differences in favour of VRBR versus rehabilitation in global perceived effect and patient satisfaction. However, significant differences were not found at short-term follow-up for global perceived effect. The interventions were supervised or performed at home. These differences could influence these variables. Garcia et al. (2021) performed an 8-week self-administered at-home behavioral skills-based VR program for chronic low back pain (CLBP). They found significant differences in favour of VRBR in global perceived effect and patient satisfaction although the intervention was performed at home without supervision. Regarding the follow-up, we only observed significant differences in favour of VRBR in Bahat et al. (2015) and that could be explained because participants performed a non-supervised home exercise programme in the postintervention period.

Immersive VR was the most used among the studies. Only one study used non-immersive VR (Rezaei et al. 2019). For this reason, we could not analyse the effects of VRBR depending on the type of VR. Therefore, although immersive VR is more common to treat patients with chronic neck pain, the evidence on which type of VR is more effective remains unclear.

4.1 VRBR in other populations

In a previous systematic review, we explored VRBR effects in CLBP (Brea-Gomez et al. 2021). We found significant differences in favour of VRBR in pain intensity and kinesiophobia postintervention and at six months follow-up. These results differ partially from the current review. Significant differences were obtained in favour of VRBR in pain intensity but not in kinesiophobia nor in the follow-up despite it being shorter (short-term follow-up vs mid-term follow-up). It should be noted that the interventions in the CLBP studies lasted longer (4 to 12 weeks), in some cases twice or trice as long, than in the chronic neck pain studies (3 to 6 weeks). Results for disability are also different. In the current review, the meta-analysis showed significant differences in favour of VRBR in disability, also at short-term follow-up, but for CLBP no significant differences were found. It should be considered that the pathology was not the same and the type of VR as well as the devices used in each case were different. Most chronic neck pain studies used immersive VR with head-mounted displays or glasses and CLBP studies used semi-immersive or non-immersive VR with systems such as Nintendo consoles or horse-riding simulators. In addition, there are differences in clinical profiles.

VRBR effects have been explored in acute conditions too. A recent systematic review and meta-analysis of RCTs (Baradwan et al. 2022) concluded that VRBR is an effective technique for improving pain management during normal labour. All included articles compared VRBR to no intervention or placebo. These results differ from ours since we did not obtain significant differences in that comparison although it was expected. Nevertheless, it should be taken into account that the type of pain and its origin differ between studies. In addition, we only included one article that compared VRBR with no intervention.

Asadzadeh et al. (2021) conducted a systematic review to evaluate VRBR effectiveness in rehabilitation. They provided evidence that show VRBR interventions had a positive impact on rehabilitation objectives and outcomes. These results coincide partially with our review. This review supports good results obtained in chronic neck pain and demonstrates that the findings we obtained are similar in other types of pathologies and in the context of rehabilitation.

4.2 Discussion with other reviews

The effectiveness of VRBR for chronic neck pain has been studied in two systematic reviews. Gumaa et al. (2019) explored VRBR effects in orthopaedic rehabilitation. They only included two articles with chronic neck pain patients (Bahat et al. 2015, 2018). These articles provided evidence of improved cervical flexion range, movement velocity and accuracy with VRBR in comparison with KT and/or no-treatment control (Gumaa et al. 2019). However, the number of included articles is limited, and we can add new information about this issue.

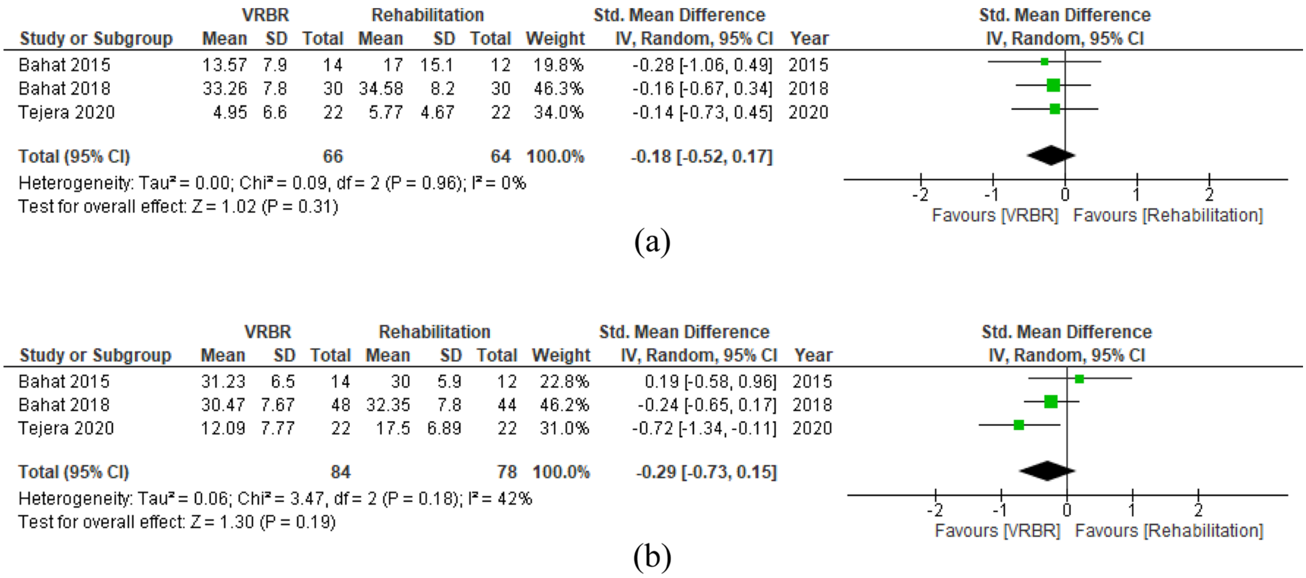
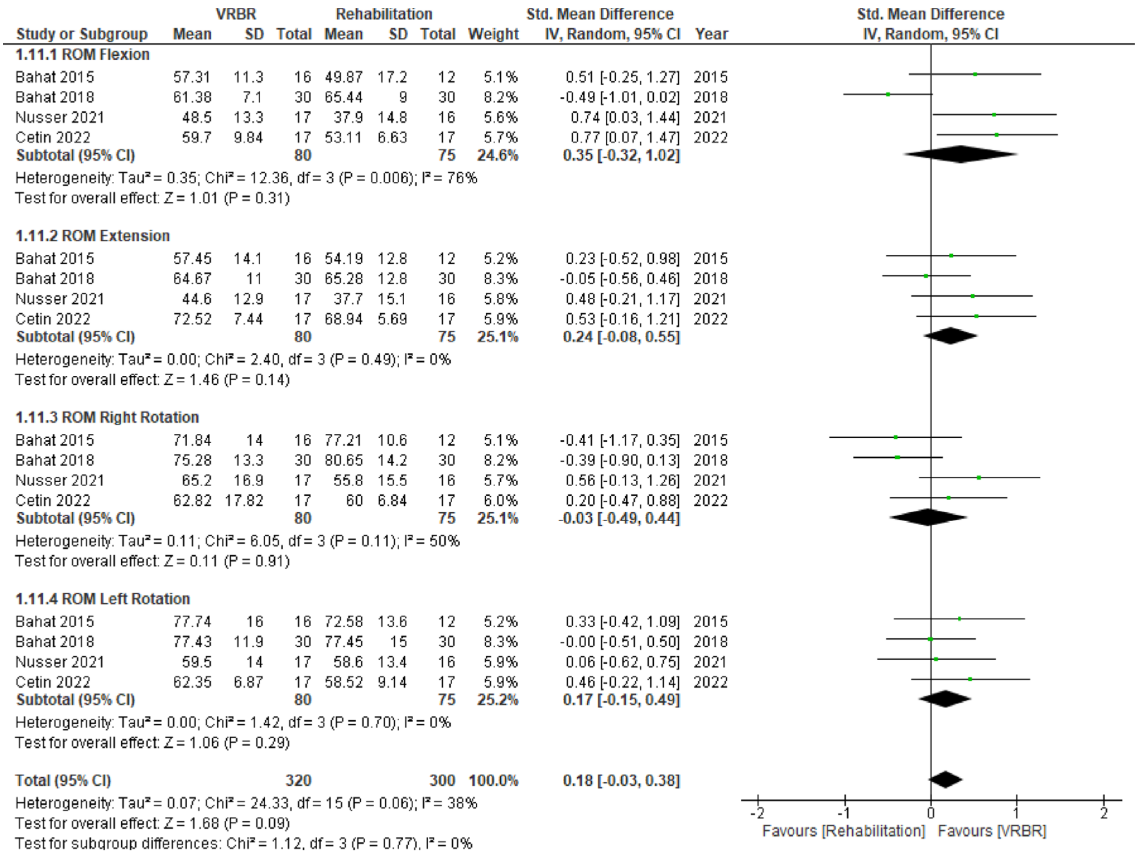


Fig. 6 Forest plot summarizing SMD and 95% CI for the effects of VRBR versus rehabilitation in chronic neck pain for kinesiophobia (**a**) and kinesiophobia at short-term follow-up (**b**). VRBR: Virtual Reality Based Rehabilitation

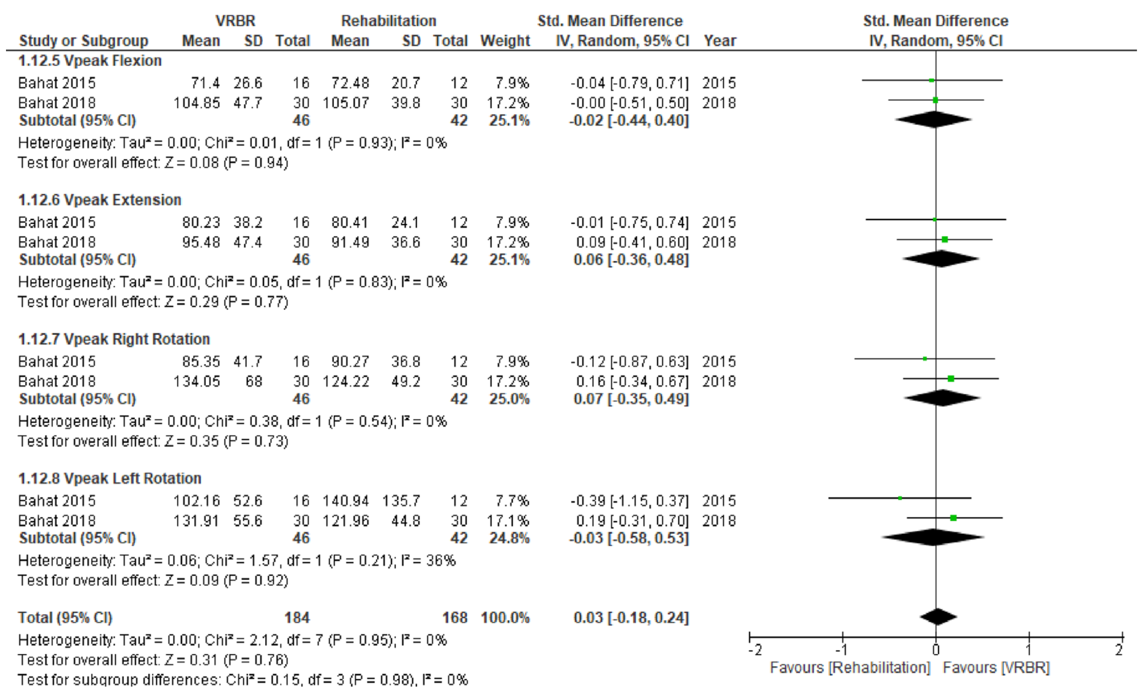
Ahern et al. (2020) investigated the effects of VRBR in chronic neck pain. On the one hand, the meta-analysis did not show significant differences in pain intensity and disability. These results differ from ours since we found significant differences in favour of VRBR for these variables. In addition, we found significant differences at short-term follow-up for disability. It could be explained because we included a greater number of articles. Besides, the meta-analysis was performed differently in each review, for example, we added subgroups and divided meta-analysis depending on the intervention that was used to compare with VRBR, in order to analyse as many comparisons included in the studies as possible. On the other hand, we can observe that other results coincide with ours. No significant differences were found in pain intensity at short-term follow-up, kinesiophobia postintervention or kinesiophobia at short-term follow-up. This may be due to meta-analysis are quite similar. Meta-analysis in both reviews obtained the same results for global perceived effect and patient satisfaction postintervention and for global perceived effect at short-term follow-up because they were conducted in the same way.

Recently, Guo et al. (2023) carried out a systematic review to study the effects of VRBR in neck pain patients. Our systematic review is performed specifically in chronic neck pain patients. Our results are partially in line with those found by Guo et al. (2023). They found significant differences in favour of VRBR for pain intensity and disability in neck pain patients. However, at short-term follow-up no significant differences were found while we also observed significant differences in favour of VRBR for disability. In addition, they found that VRBR significantly decreased pain intensity in patients with chronic neck pain. This is consistent with our findings. We also obtained a significant improvement in global perceived effect and patient satisfaction. They also found significant differences for kinesiophobia and cervical kinematic parameters. We did not encounter significant differences in those outcomes so these findings differ from ours.

The number of included studies should be considered since we only considered chronic pain studies. They reported advantages to multimodal intervention. However, regarding our results, evidence is inconclusive in chronic neck pain patients.

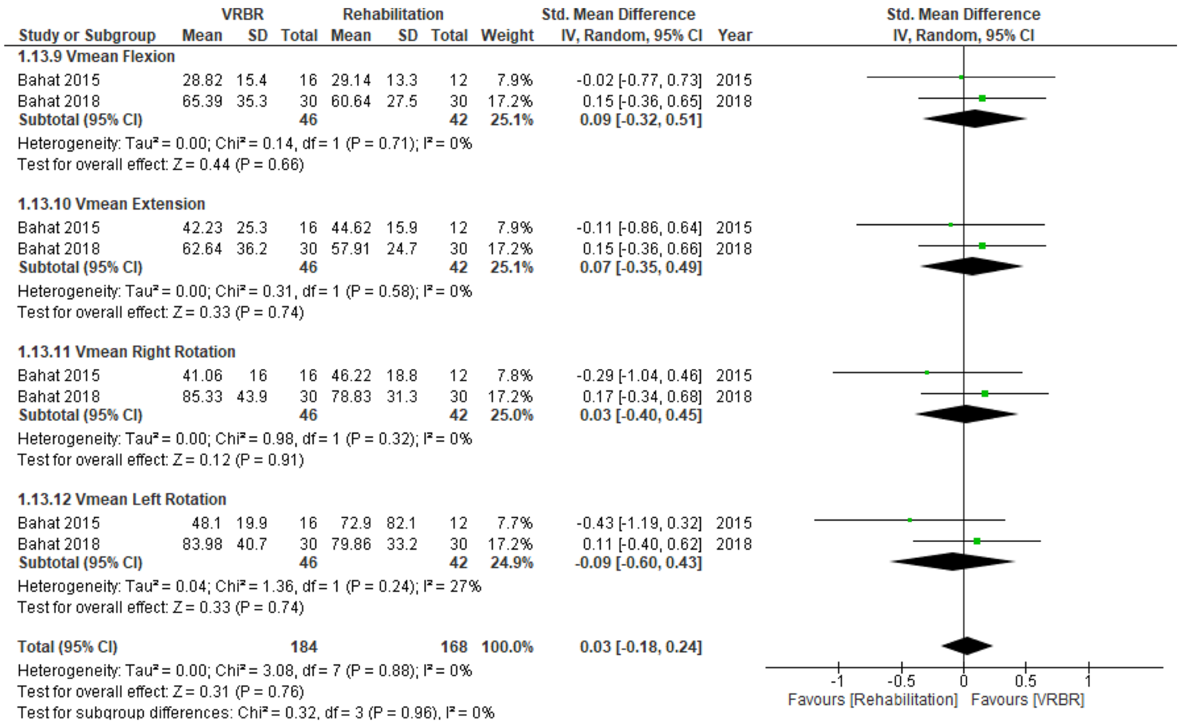


(a)

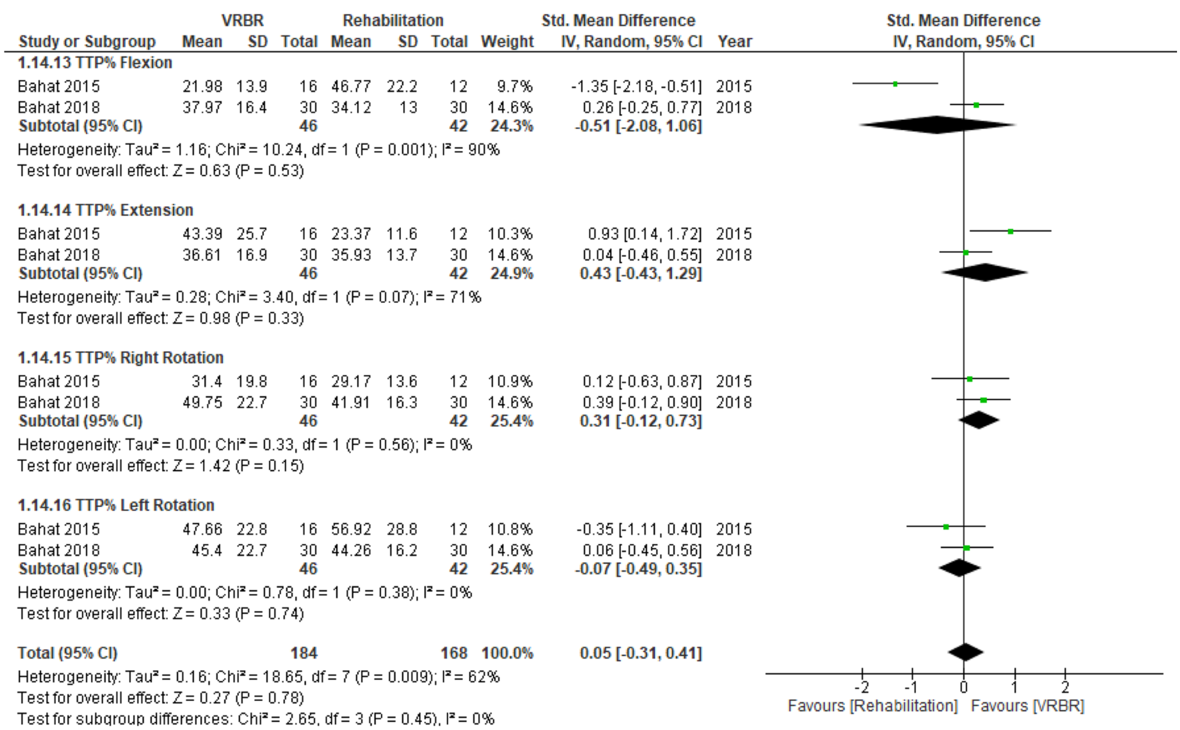


(b)

Fig. 7 Forest plot summarized SMD and 95% CI for the effect of VRBR versus rehabilitation in chronic neck pain for cervical kinematics: ROM (**a**), Vpeak (**b**), Vmean (**c**), TTP% (**d**). *ROM* Range of Motion, *VRBR* Virtual Reality Based Rehabilitation, *Vpeak* peak velocity, *Vmean* mean velocity, *TTP%* time to peak velocity percentage

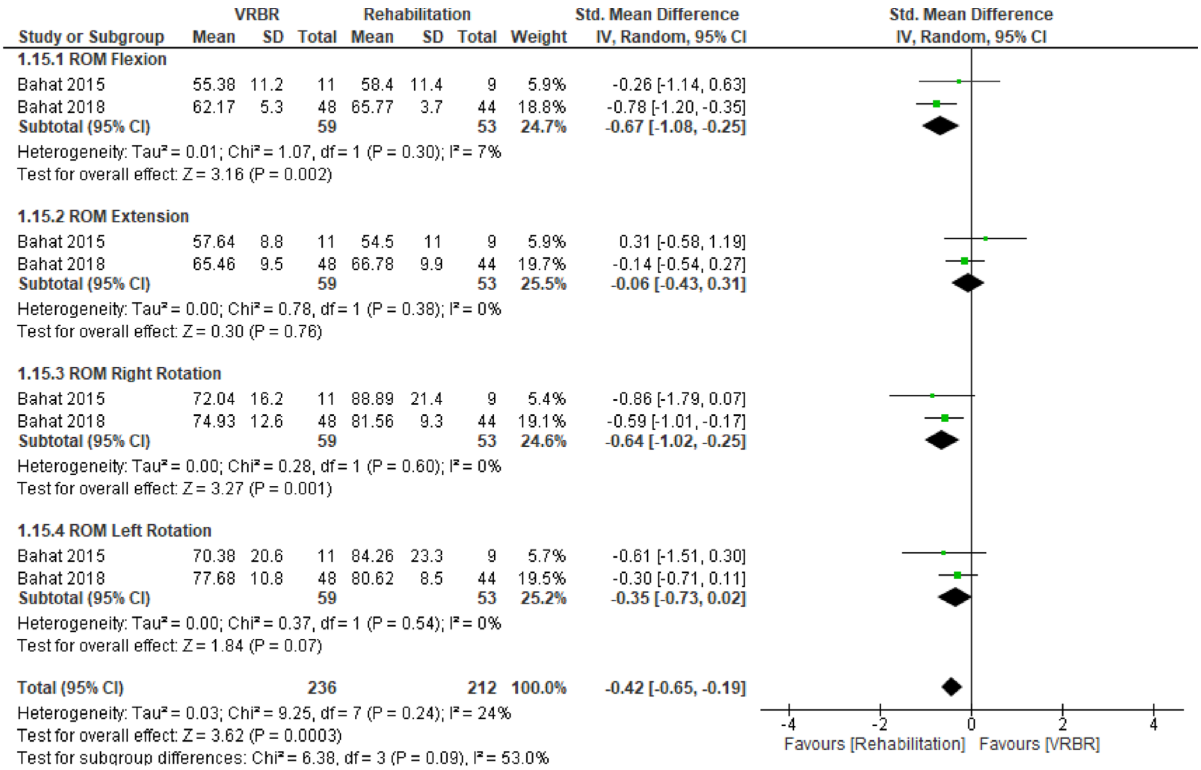


(c)

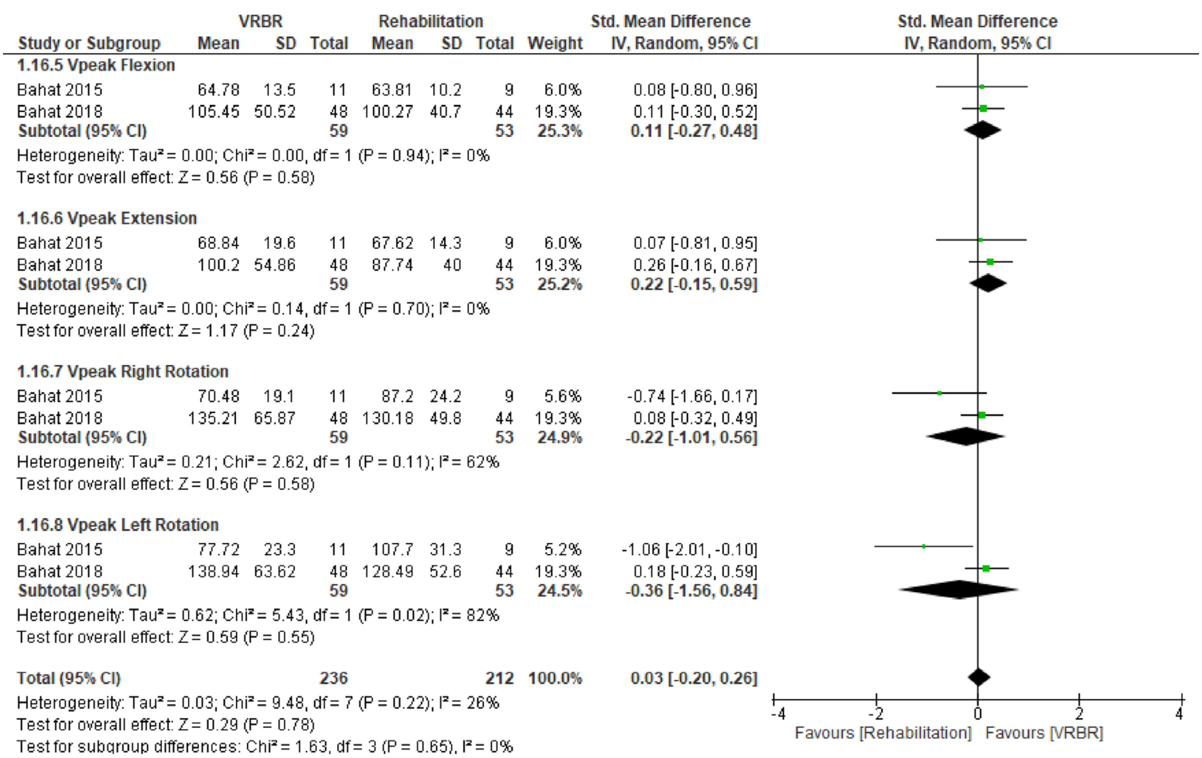


(d)

Fig. 7 (continued)

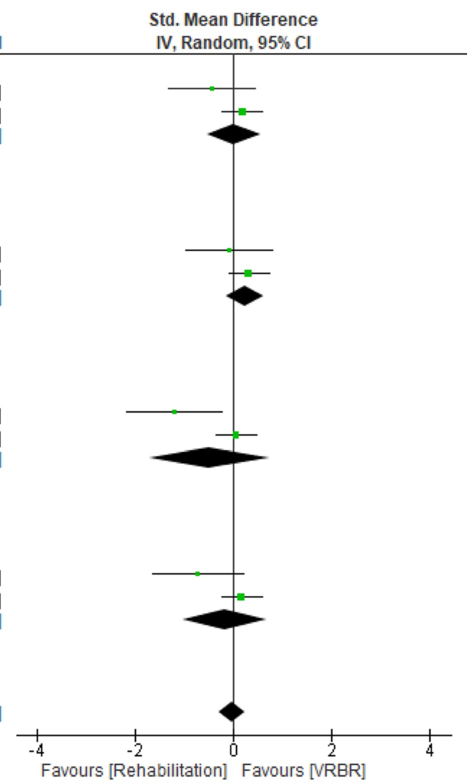


(a)



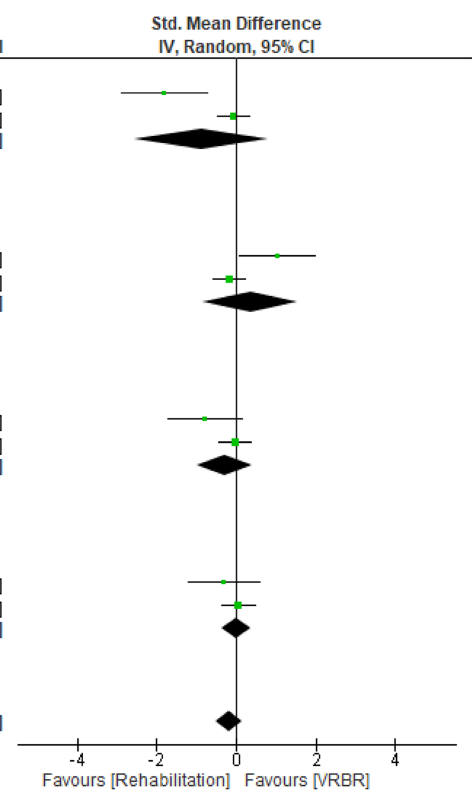
(b)

Fig. 8 Forest plot summarized SMD and 95% CI for the effect of VRBR versus rehabilitation in chronic neck pain for cervical kinematics at short-term follow-up: ROM (**a**), Vpeak (**b**), Vmean (**c**), TTP% (**d**). *ROM* Range of Motion, *VRBR* Virtual Reality Based Rehabilitation, *Vpeak* peak velocity, *Vmean* mean velocity, *TTP%* time to peak velocity percentage



Study or Subgroup	VRBR Mean	VRBR SD	VRBR Total	Rehabilitation Mean	Rehabilitation SD	Rehabilitation Total	Weight	Std. Mean Difference IV, Random, 95% CI
1.17.9 Vmean Flexion								
Bahat 2015	21.56	9.2	11	25.86	9.6	9	7.1%	-0.44 [-1.33, 0.45]
Bahat 2018	66.03	34.13	48	60.42	28.7	44	18.2%	0.18 [-0.23, 0.59]
Subtotal (95% CI)			**59**			**53**	**25.3%**	**0.00 [-0.54, 0.54]**
Heterogeneity: Tau² = 0.06; Chi² = 1.50, df = 1 (P = 0.22); I² = 33%								
Test for overall effect: Z = 0.01 (P = 0.99)								
1.17.10 Vmean Extension								
Bahat 2015	35.55	14.3	11	36.6	8.1	9	7.2%	-0.08 [-0.97, 0.80]
Bahat 2018	65.9	38.33	48	55.46	27	44	18.1%	0.31 [-0.10, 0.72]
Subtotal (95% CI)			**59**			**53**	**25.3%**	**0.24 [-0.13, 0.61]**
Heterogeneity: Tau² = 0.00; Chi² = 0.63, df = 1 (P = 0.43); I² = 0%								
Test for overall effect: Z = 1.26 (P = 0.21)								
1.17.11 Vmean Right Rotation								
Bahat 2015	33.41	17.4	11	52.25	11.5	9	6.2%	-1.20 [-2.17, -0.22]
Bahat 2018	87.72	47.78	48	85.46	37.7	44	18.2%	0.05 [-0.36, 0.46]
Subtotal (95% CI)			**59**			**53**	**24.4%**	**-0.49 [-1.71, 0.72]**
Heterogeneity: Tau² = 0.64; Chi² = 5.38, df = 1 (P = 0.02); I² = 81%								
Test for overall effect: Z = 0.79 (P = 0.43)								
1.17.12 Vmean Left Rotation								
Bahat 2015	40.37	18.6	11	52.47	12.4	9	6.8%	-0.72 [-1.63, 0.20]
Bahat 2018	85.87	48.92	48	78.31	40.5	44	18.2%	0.17 [-0.24, 0.58]
Subtotal (95% CI)			**59**			**53**	**25.0%**	**-0.18 [-1.02, 0.67]**
Heterogeneity: Tau² = 0.26; Chi² = 2.99, df = 1 (P = 0.08); I² = 67%								
Test for overall effect: Z = 0.41 (P = 0.68)								
Total (95% CI)			**236**			**212**	**100.0%**	**-0.03 [-0.30, 0.24]**
Heterogeneity: Tau² = 0.06; Chi² = 12.46, df = 7 (P = 0.09); I² = 44%								
Test for overall effect: Z = 0.23 (P = 0.82)								
Test for subgroup differences: Chi² = 1.98, df = 3 (P = 0.58), I² = 0%								

(c)



Study or Subgroup	VRBR Mean	VRBR SD	VRBR Total	Rehabilitation Mean	Rehabilitation SD	Rehabilitation Total	Weight	Std. Mean Difference IV, Random, 95% CI
1.18.13 TTP% Flexion								
Bahat 2015	17.14	12.2	11	43.09	15.4	9	6.8%	-1.81 [-2.89, -0.73]
Bahat 2018	35.41	13.2	48	36.6	14.6	44	17.0%	-0.08 [-0.49, 0.32]
Subtotal (95% CI)			**59**			**53**	**23.8%**	**-0.87 [-2.56, 0.81]**
Heterogeneity: Tau² = 1.32; Chi² = 8.58, df = 1 (P = 0.003); I² = 88%								
Test for overall effect: Z = 1.01 (P = 0.31)								
1.18.14 TTP% Extension								
Bahat 2015	35.69	14	11	21.31	12.2	9	8.0%	1.04 [0.09, 1.99]
Bahat 2018	33.75	9.9	48	35.73	11.3	44	17.0%	-0.19 [-0.60, 0.22]
Subtotal (95% CI)			**59**			**53**	**25.0%**	**0.35 [-0.84, 1.54]**
Heterogeneity: Tau² = 0.61; Chi² = 5.38, df = 1 (P = 0.02); I² = 81%								
Test for overall effect: Z = 0.57 (P = 0.57)								
1.18.15 TTP% Right Rotation								
Bahat 2015	30.07	27.3	11	48.46	13.5	9	8.4%	-0.79 [-1.71, 0.13]
Bahat 2018	46.94	20.5	48	47.5	12.1	44	17.0%	-0.03 [-0.44, 0.38]
Subtotal (95% CI)			**59**			**53**	**25.4%**	**-0.29 [-1.00, 0.41]**
Heterogeneity: Tau² = 0.16; Chi² = 2.17, df = 1 (P = 0.14); I² = 54%								
Test for overall effect: Z = 0.82 (P = 0.41)								
1.18.16 TTP% Left Rotation								
Bahat 2015	42.17	26.8	11	50.54	23.1	9	8.8%	-0.32 [-1.21, 0.57]
Bahat 2018	41.34	21	48	40.26	16.6	44	17.0%	0.06 [-0.35, 0.47]
Subtotal (95% CI)			**59**			**53**	**25.8%**	**-0.01 [-0.38, 0.36]**
Heterogeneity: Tau² = 0.00; Chi² = 0.56, df = 1 (P = 0.45); I² = 0%								
Test for overall effect: Z = 0.05 (P = 0.96)								
Total (95% CI)			**236**			**212**	**100.0%**	**-0.17 [-0.51, 0.16]**
Heterogeneity: Tau² = 0.13; Chi² = 18.36, df = 7 (P = 0.01); I² = 62%								
Test for overall effect: Z = 1.02 (P = 0.31)								
Test for subgroup differences: Chi² = 1.84, df = 3 (P = 0.61), I² = 0%								

(d)

Fig. 8 (continued)

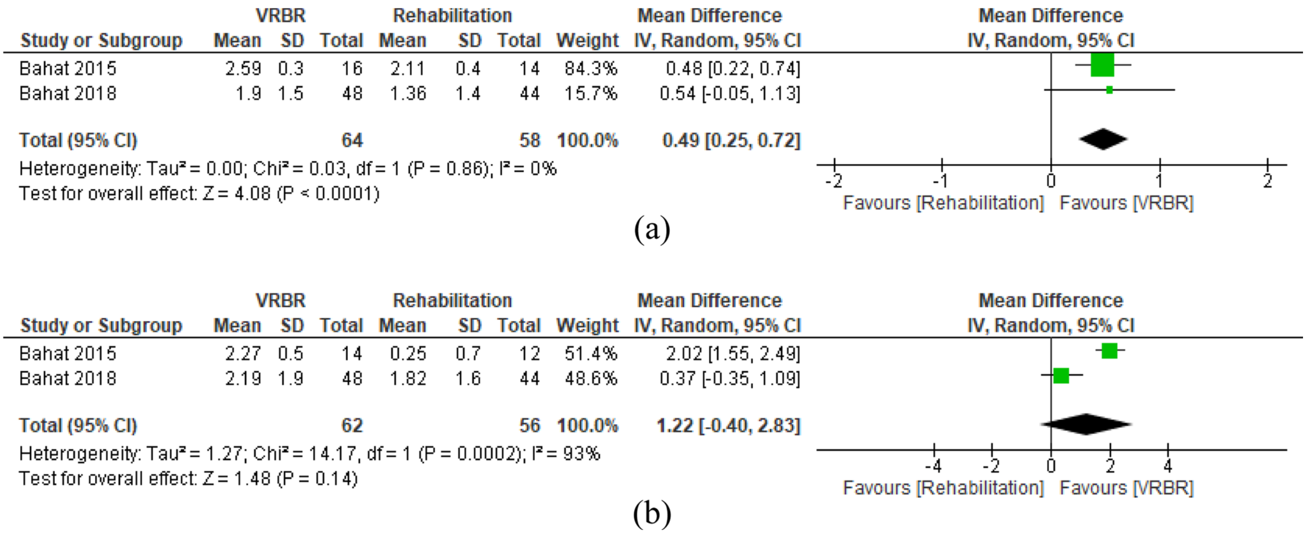


Fig. 9 Forest plot summarizing MD and 95% CI for the effects of VRBR versus rehabilitation in chronic neck pain for global perceived effect (**a**) and global perceived effect at short-term follow-up (**b**). *VRBR* Virtual Reality Based Rehabilitation

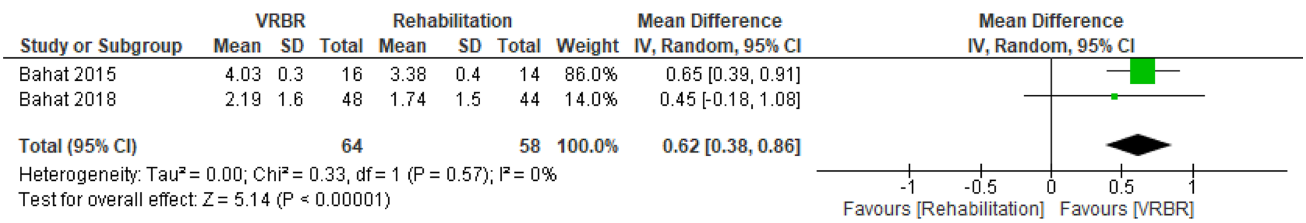


Fig. 10 Forest plot summarizing MD and 95% CI for the effects of VRBR versus rehabilitation in chronic neck pain for patient satisfaction postintervention. *VRBR* Virtual Reality Based Rehabilitation

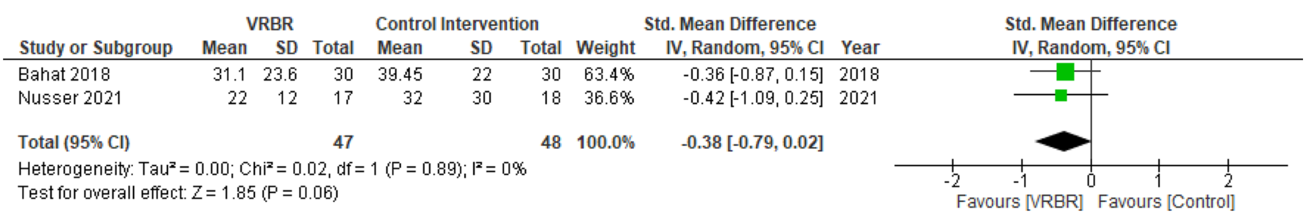


Fig. 11 Forest plot summarizing SMD and 95% CI for the effects of VRBR versus control intervention in chronic neck pain for pain intensity. *VRBR* Virtual Reality Based Rehabilitation

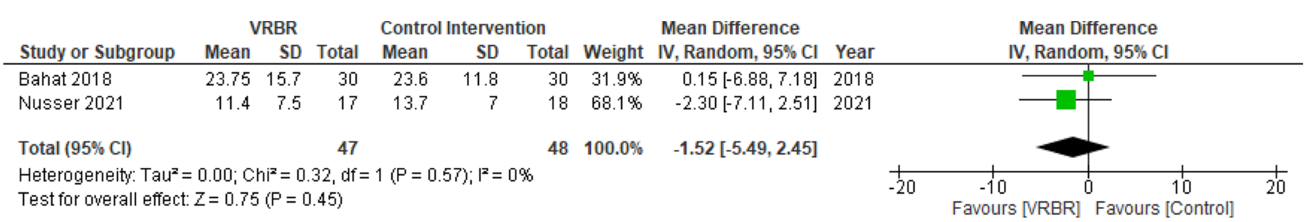


Fig. 12 Forest plot summarizing MD and 95% CI for the effects of VRBR versus control intervention in chronic neck pain for disability. *VRBR* Virtual Reality Based Rehabilitation

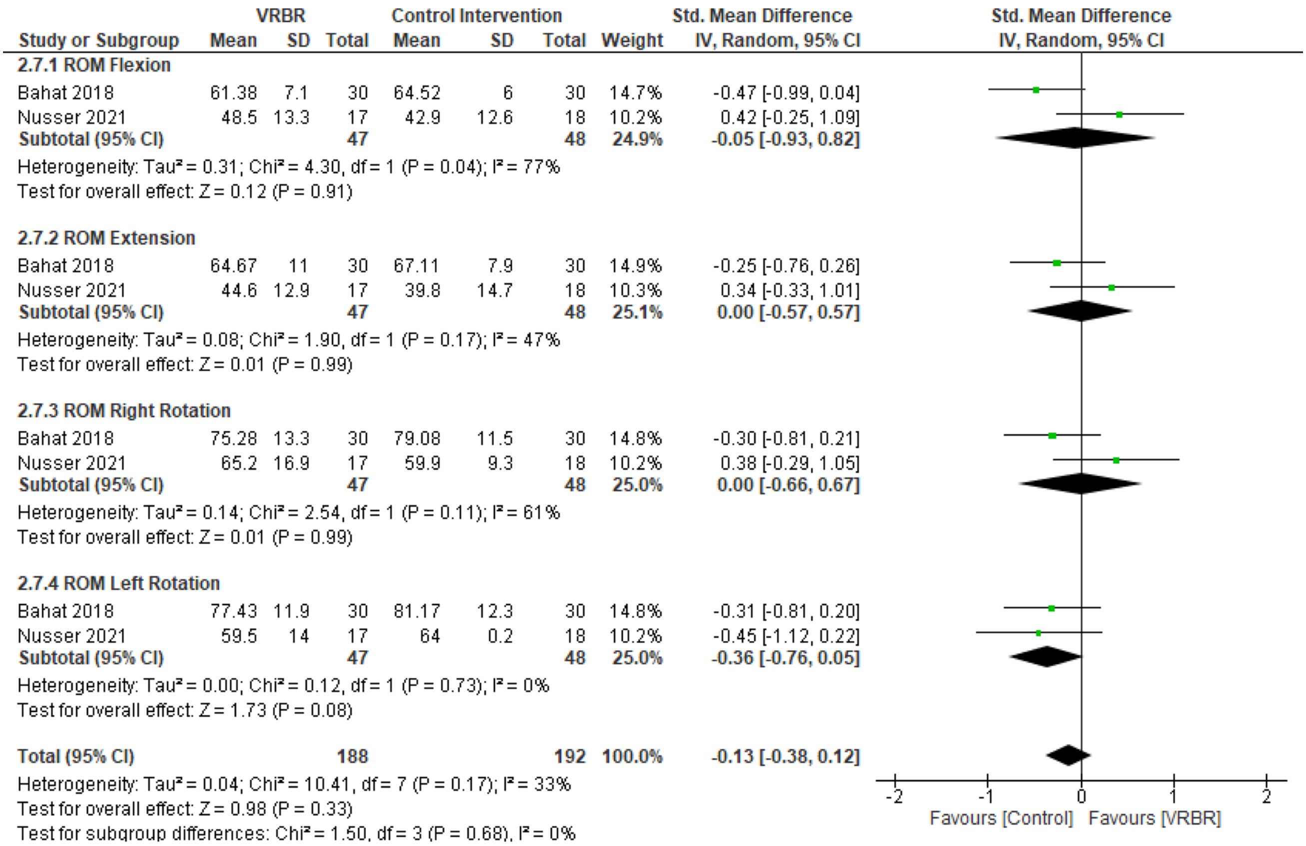


Fig. 13 Forest plot summarizing SMD and 95% CI for the effects of VRBR versus control intervention in chronic neck pain for ROM. *VRBR* Virtual Reality Based Rehabilitation, *ROM* Range of Motion

4.3 Strengths and limitations

Strengths: We use the PRISMA guidelines (Page et al. 2021) and PICOS strategy. Meta-analysis provides important information about the effectiveness of VRBR specifically in chronic neck pain patients including a subgroup analysis in order to clarify different issues about these interventions. Methodological quality was evaluated with one of the top six quality scales (Downs et al. 1998). Most studies scored good quality. The RoB-2 (Higgins et al. 2019) was used to assess risk of bias. We registered the protocol (PROSPERO: CRD42020222129).

Limitations: Although the six studies (Bahat et al. 2015, 2018; Rezaei et al. 2019; Tejera et al. 2020; Nusser et al. 2021; Cetin et al. 2022) included participants with chronic neck pain, the origin and characteristics were different between some of them, and this could have an impact on the results. In addition, interventions were heterogeneous and making subgroups was complicated. Additionally, in most studies the sample size was relatively small and none of studies included mid-term or long-term assessment. Another limitation was the low number of included studies. In fact, publication bias was not assessed because of too few included studies. Last, the interpretation of this meta-analysis must be cautious because three studies obtained a high risk of bias. The main problems were deviations from intended interventions and measurement of the outcome. Patients could not be blinded in any study.

Initially, a general spinal pain systematic review was proposed. Due to the heterogeneity of the included studies (neck pain, low back pain…) we decided to divide the review to extract the most relevant information and draw conclusions for each pathology specifically. In this case, most studies focused on CLBP on the one hand and chronic neck pain on the other hand. We have already published a specific review on CLBP (Brea-Gómez et al. 2021). In the current review, we present specific data on chronic neck pain.

4.4 Clinical implications and future research

VRBR could be used in clinical practice in order to improve pain intensity and disability in patients with chronic neck pain. Effects are maintained at short-term follow-up for disability. The evidence of VRBR in mid-term and in long-term follow-up has not been studied yet so future research should explore effects of VRBR in both time-point assessments. Regarding the type of VR used in these interventions, all the included studies, except Rezaei et al. (2019), used immersive VR with favourable results. These VR devices, such as VR glasses, are commercially available. However, subgroup analysis based on the type of VR could not be performed so the evidence about different types of VR remains unclear. In addition, half of the studies reported adverse effects or unpleasant sensations produced by the VR device. It would be necessary to investigate the adverse effects as well as different types of VR. There are conflicting results on whether VRBR should be applied alone or combined with other intervention. The evidence seems to indicate better effects when VRBR is combined with other intervention, though the results are not conclusive. More research on VRBR interventions is needed.

5 Conclusions

In conclusion, the available evidence has demonstrated that VRBR can significantly improve pain intensity and disability associated with chronic neck pain. In addition, patients in VRBR group show a greater global perceived effect and satisfaction with the treatment. These results are maintained at short-term follow-up for disability. However, no significant differences were obtained for kinesiophobia. Regarding cervical kinematic parameters, the evidence remains limited since no significant differences were found. Nevertheless, few significant differences were found in favour of rehabilitation at short-term follow-up. There seems to be a need to investigate VRBR effects in mid-term and long-term follow-up due to the lack of information on this topic in published studies. Most of the included studies have a good methodological quality, but we only included six, so it would be necessary to carry out more studies with a similar or better quality. Finally, it is essential to explore the different VR systems with the purpose of reducing side effects as much as possible.

Appendix 1: Search strategy studies

DATABASE	Cinahl
DATE	07/08/2023
SEARCH STRATEGY	#1 AND #2
#1	AB (“neck pain”[Mesh] OR “neck pain” OR “cervical pain” OR “spine pain” OR “spinal pain”)
#2	AB (“Video Games”[Mesh] OR “video game*” OR “videogame*” OR “Gaming” OR “Game” OR “games” OR “Wii” OR “Nintendo” OR “Kinect” OR “Xbox” OR “PlayStation” OR “Virtual Reality”[Mesh] OR “virtual reality” OR “Virtual Reality Exposure Therapy”[Mesh] OR “exergame*” OR “gamification” OR “virtual” OR “computer-based” OR “augmented reality” OR “head-mounted display” OR “oculus rift” OR “oculus quest” OR “HTC Vive” OR “Steam VR” OR “leap motion”)
DATABASE	Medline (Via PubMed)
DATE	07/08/2023
SEARCH STRATEGY	#1 AND #2
#1	(“neck pain”[Mesh] OR “neck pain” OR “cervical pain” OR “spine pain” OR “spinal pain”)
#2	(“Video Games”[Mesh] OR “video game*” OR “videogame*” OR “Gaming” OR “Game” OR “games” OR “Wii” OR “Nintendo” OR “Kinect” OR “Xbox” OR “PlayStation” OR “Virtual Reality”[Mesh] OR “virtual reality” OR “Virtual Reality Exposure Therapy”[Mesh] OR “exergame*” OR “gamification” OR “virtual” OR “computer-based” OR “augmented reality” OR “head-mounted display” OR “oculus rift” OR “oculus quest” OR “HTC Vive” OR “Steam VR” OR “leap motion”)
DATABASE	Scopus
DATE	07/08/2023
SEARCH STRATEGY	#1 AND #2
#1	TITLE-ABS-KEY (“neck pain” OR “cervical pain” OR “spine pain” OR “spinal pain”)
#2	TITLE-ABS-KEY (“video game*” OR “videogame*” OR “Gaming” OR “Game” OR “games” OR “Wii” OR “Nintendo” OR “Kinect” OR “Xbox” OR “PlayStation” OR “virtual reality” OR “Virtual Reality Exposure Therapy” OR “exergame*” OR “gamification” OR “virtual” OR “computer-based” OR “augmented reality” OR “head-mounted display” OR “oculus rift” OR “oculus quest” OR “HTC Vive” OR “Steam VR” OR “leap motion”)
DATABASE	Web Of Science

DATE	07/08/2023
SEARCH STRATEGY	#1 AND #2
#1	TS = (“neck pain”[Mesh] OR “neck pain” OR “cervical pain” OR “spine pain” OR “spinal pain”)
#2	TS = (“Video Games”[Mesh] OR “video game*” OR “videogame*” OR “Gaming” OR “Game” OR “games” OR “Wii” OR “Nintendo” OR “Kinect” OR “Xbox” OR “PlayStation” OR “Virtual Reality”[Mesh] OR “virtual reality” OR “Virtual Reality Exposure Therapy”[Mesh] OR “exergame*” OR “gamification” OR “virtual” OR “computer-based” OR “augmented reality” OR “head-mounted display” OR “oculus rift” OR “oculus quest” OR “HTC Vive” OR “Steam VR” OR “leap motion”)

Appendix 2: Search strategy ongoing trials

DATABASE	ClinicalTrials.gov
DATE	08/08/2023
STRATEGY	(“neck pain”) AND (“video games” OR “virtual reality” OR “virtual reality exposure therapy”) Filter: study type → interventional (clinical trial)
DATABASE	ICTRP
DATE	08/08/2023
STRATEGY	“neck pain” AND “virtual reality” “neck pain” AND “virtual reality exposure therapy” “neck pain” AND “video games”
DATABASE	ISRCTN registry
DATE	08/08/2023
STRATEGY	“neck pain” AND “virtual reality” “neck pain” AND “virtual reality exposure therapy” “neck pain” AND “video games”

Appendix 3: Excluded studies in the last screening with reasons for exclusion (n = 17)

Article	Reason for exclusion
Therapeutic exercise based on videogames to improve neck pain	Not randomized trial
Self-kinematic training for flight-associated neck pain: a randomized controlled trial	No chronic neck pain
The effect of cranio-cervical flexion training and rest breaks on neck pain and functional performance in visual display unit users	Not using VRBR as treatment
Use of virtual reality feedback for patients with chronic neck pain and kinesiophobia	Not randomized trial
Exercise programs targeting scapular kinematics and stability are effective in decreasing neck pain: a critically appraised topic	Not randomized trial
Effects of interactive virtual reality device on cervical pain and neck function in forward head posture	No chronic neck pain
Virtual reality exercises in an interdisciplinary rehabilitation programme for persons with chronic neck pain: a feasibility study	Not randomized trial
Bogus visual feedback alters onset of movement-evoked pain in people with neck pain	Not randomized trial
Using visuo-kinetic virtual reality to induce illusory spinal movement: the MoOVi Illusion	No chronic neck pain
A serious exergame for patients suffering from chronic musculoskeletal back and neck pain: a pilot study	Not randomized trial
Using visual feedback manipulation in virtual reality to influence pain-free range of motion in people with nonspecific neck pain	Not randomized trial
A system for head-neck rehabilitation exercises based on serious gaming and virtual reality	Not randomized trial
Virtual reality and applications to treating neck pain	Not randomized trial
Predictors for positive response to home kinematic training in chronic neck pain	Not randomized trial
Exercise therapy program using immersive virtual reality for people with non-specific chronic neck pain: a 3 month retrospective open pilot and feasibility study	Not randomized trial

Article	Reason for exclusion
Development of serious games for the rehabilitation of the human vertebral spine for home care	Not randomized trial
The use of augmented reality in the teaching and training of basic exercises involved in the non-surgical treatment of neck pain	Not randomized trial

Appendix 4: Characteristics of included registry entries or ongoing trials (n = 10)

Number	Article	Recruitment status
NCT03987334	Virtual reality rehabilitation in neck pain subjects	Recruiting
NCT05244681	Experiences of a home-based virtual reality serious game in people with chronic non-specific neck pain	Recruiting
NCT05829564	Virtual reality and cervical mobilization	Recruiting
NCT05662683	The effect of virtual reality and distraction cards on pain	Recruiting
CTRI/2021/11/038130	Effect of stabilization sensorimotor exercise and virtual reality in person with neck pain	Not recruiting
CTRI/2021/10/037376	Effect of stabilization sensorimotor exercise and Virtual reality on pain, movement, function and stability in neck pain	Not recruiting
ChiCTR2000040132	Virtual reality training for individuals with chronic neck pain: a randomized controlled trial	Not recruiting
ChiCTR1900024327	Virtual reality training for individuals with chronic neck pain: a randomized controlled trial	Not recruiting
CTRI/2018/07/014733	Immediate and short term effect of virtual reality training on pain and range of motion in patients having neck pain	Not recruiting
RBR-6rrbtsd	Effect of virtual reality in the treatment of chronic neck pain	Recruiting

Appendix 5: Downs and Black scores included studies

References	Study quality										External validity			Study bias							Confounding and selection bias						Study power	Total	Quality
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27		
Bahat et al. (2015)	1	1	1	1	1	1	1	1	0	0	1	1	1	0	1	1	1	1	1	1	1	1	1	1	0	0	0	21	Good
Bahat et al. (2018)	1	1	1	1	2	1	1	1	0	0	0	0	1	0	1	1	1	1	1	1	0	0	1	1	1	0	0	19	Fair
Rezaei et al. (2019)	1	1	1	1	2	1	1	1	1	1	1	1	0	0	1	1	1	1	1	1	1	0	1	1	0	1	1	24	Good
Tejera et al. (2020)	1	1	1	1	2	1	1	0	1	1	1	1	0	0	0	1	1	1	1	1	1	1	1	0	1	1	1	23	Good
Nusser et al. (2021)	1	1	1	1	1	1	1	1	1	1	0	1	1	0	0	1	1	1	1	1	1	1	1	0	0	1	0	21	Good
Cetin et al. (2022)	1	1	1	1	1	1	1	1	1	1	0	1	1	0	0	1	1	1	1	1	1	1	1	0	0	0	1	21	Good

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Declarations

Conflict of interest The authors have no relevant financial or non-financial interests to disclose.

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