Archives de pédiatrie 31 (2024) 217–223

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Practice guidelines

Guidelines of the French Society of Otorhinolaryngology and Head and Neck Surgery (SFORL) for vestibular rehabilitation in children with vestibular dysfunction. A systematic review

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ARTICLE INFO

Article History:
Received 14 October 2023
Revised 20 January 2024
Accepted 25 February 2024
Available online 1 May 2024

Keywords:
Vestibular rehabilitation
Physiotherapy
Vestibular impairment
Children

ABSTRACT

Introduction: The consequence of complete or partial uncompensated vestibular dysfunction in children is usually balance disorders, with the risk of falls and increased fatigue, particularly during tasks requiring postural control. The aim of these recommendations is to establish guidelines for vestibular rehabilitation (VR) in children with vestibular impairment.
Material and methods: The guidelines were developed based on a systematic review of the international literature, validated by a multidisciplinary group of French-speaking otorhinolaryngologists, scientists, and physiotherapists. They are classified as grade A, B, C, or expert opinion according to a decreasing level of scientific evidence.
Results: A PubMed search of studies published between January 1990 and December 2021 was carried out using the keywords "vestibular," "rehabilitation," and "children". After filtering and reviewing the articles, a total of 10 publications were included to establish the recommendations.
Conclusion: It is recommended that a vestibular assessment be carried out before VR, including a study of vestibulo-ocular reflex, otolithic function, and postural control. In cases of vestibular dysfunction, physiotherapy treatment is recommended from an early age to train different aspects of postural control, including anticipatory and reactive postural adjustments. VR adapted to the pediatric population is recommended for children whose vestibular dysfunction leads to functional disorders or symptoms of vertigo for those who have suffered head trauma. It is recommended that children with bilateral vestibular impairment be treated using gaze stabilization exercises for adaptation and substitution. Optokinetic stimulation and virtual reality are not recommended for children and young adolescents.
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1. Introduction

The vestibular organs are specialized accelerometers for quantifying head movement and position. Through the saccular and utricular maculae, they assess gravitational or linear accelerations during translational movements; through the semicircular canals, they determine active or passive angular accelerations of the head. Ongoing postural sensory and motor adjustments via the vestibulospinal system are required to ensure and adopt the most appropriate sensory strategy and motor response in order to restore balance at all times. Vertiginous symptoms in children are rarely described, as they do not verbalize their complaints until they reach a certain age [1]. Instead, parents may report balance problems or witness delayed postural–motor development.

A study in the United States shows that the prevalence of vertigo and balance disorders in children is 5.3 %, ranging from 4.1 % in the 3–5-year age group to 7.5 % after the age of 15 [2]. In a recent study of 1037 children presenting with instability, vestibular involvement was detected in 36.5 % of cases [3]. The most common etiologies include inner ear malformations, labyrinthine contusions, vestibular neuritis, meningitis, or ototoxicity [3,4]. According to Wiener-Vacher

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https://doi.org/10.1016/j.arcped.2024.02.006
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et al., vestibular migraine is considered the most common cause of vertiginous symptomatology in children and adolescents; other possible etiologies include visual disorders, anxiety-related manifestations, or neurological disorders (e.g., encephalitis, degenerative diseases, and brain tumors; cerebral palsy (CP) was not mentioned) [3]. Dysfunction may be due to lesions affecting the peripheral (bilateral or unilateral) or central vestibular structures.

Vestibular dysfunction may affect up to 50 % of children with sensorineural hearing loss (SNHL) [5]. In cases of profound bilateral SNHL, cochlear implantation (CI) is an effective solution for restoring hearing; because there is a risk of vestibular dysfunction associated with CI insertion, the pre-implant assessment includes a vestibular and postural control assessment to look for delayed motor development [6].

The vestibular system enables gaze stability during head movements through the vestibulo-ocular reflex (VOR) originating from the semicircular canals. It also participates in the perception of verticality and is involved in producing muscular synergies necessary for postural control and orientation via vestibulospinal reflexes. Thus, the vestibular system plays a crucial role in postural orientation and elaborates various postural adjustments essential for acquiring the different stages of postural–motor development. Axial hypotonia may be observed during the first months of life in children with congenital vestibular dysfunction, particularly when otolith dysfunction occurs [7]. Children with congenital vestibular dysfunction or malfunction in early infancy may have motor delays that do not usually recover without rehabilitation [8]. The age of onset of vestibular dysfunction and the earliness of appropriate rehabilitation may influence the development of postural skills [9].

The consequence of complete or partial uncompensated vestibular dysfunction in children is usually balance disorders, with the risk of falls and increased fatigue, particularly during tasks requiring postural control [8]. A deficit in the VOR leads to a failure to stabilize the gaze during rapid head movements, which can decrease dynamic visual acuity (DVA) and produce a sensation of visual blur that may correspond to oscillopsia [10]. Vestibular dysfunction in childhood is also thought to affect cognitive development [11–14].

To date, the French Society of Otorhinolaryngology and Head and Neck Surgery has not formulated any guidelines for the rehabilitation of vestibular impairments in children. The aim of these recommendations is to establish guidelines for vestibular rehabilitation (VR) in this population.

2. Methods

The guidelines were developed based on a systematic review of the international literature, validated by a multidisciplinary group of French-speaking otorhinolaryngologists, scientists, and physiotherapists. These pediatric recommendations are part of a separate chapter of a large-scale multidisciplinary project by the French Society of Otorhinolaryngology and Head and Neck Surgery to develop recommendations on the role of rehabilitation in the management of vestibular vertigo[1]. An independent group of external reviewers validated all the recommendations. The review was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [15]. The review was not registered on PROSPERO, and the review protocol was not prepared.

2.1. Search strategy

We conducted a review of the literature on the PubMed database from 1990 to 2021 by combining the terms "vestibular," "rehabilitation," and "children." In line with the French Health Authority recommendations,[2] articles were ranked as 1, 2, 3, or 4 by decreasing levels of evidence and graded A, B, C, or expert opinion according to the data available in the literature.

2.2. Study selection

All studies of VR in children with vestibular impairment were selected. Studies in which VR was evaluated using precisely described intervention protocols, over a short or long duration, were eligible for inclusion. Duplicates and articles written in languages other than English were excluded. Studies with overlapping study populations and patients with possible central vestibular pathway involvement were not excluded. All the steps in the selection and evaluation of the quality of the papers were carried out by two researchers (P.R. and J. O-S.), who worked independently; no automation tool was used. Cases of disagreement were referred to a third person to make the final decision (H.T-V.).

2.3. Quality assessment

Two authors independently assessed the risk of bias (RoB; P.R. and J.O-S.). We used the ROBINS-I tool (Risk of Bias in Non-randomized Studies—of Interventions) to evaluate the risk of bias. The tool consists of seven domains: confounding, selection of participants, classification of interventions, deviation from intended intervention, missing data, measurement of outcomes, and selection of reported results. The criteria were defined and adapted to our research question about rehabilitation of vestibular impairments in children. Items were scored as low risk of bias, moderate risk of bias, serious risk of bias, or unclear based on the guidelines of the ROBINS-I tool. Consensus was reached after discussion between the two reviewers.

3. Results

3.1. Search strategy and study selection

Relevant current publications in peer-reviewed journals were sourced through a computerized literature search. The process of article selection was based on PRISMA. A PubMed search for articles published between January 1990 and December 2021 using the keywords "vestibular," "rehabilitation," and "children" yielded 513 results; additional filters were used after taking into account articles on the human population (n = 453) and whether they were written in English or French, with 416 articles being selected. In total, 394 articles were excluded because they did not fall within the scope of the study: 368 were off topic, 15 concerned the adult population, seven did not concern children with vestibular impairment, and four were case reports. Finally, 22 articles were assessed. After reading these 22 articles, an additional publication was added that was referenced in the articles. After assessing articles for eligibility, 13 were excluded: four articles did not deal with clearly defined vestibular rehabilitation techniques, two articles comprised mixed groups of adult and pediatric patients, five articles did not study children with systematic vestibular involvement, and two publications were general non-systematic reviews with no new data. A total of 10 articles were therefore included for the review. The PRISMA flowchart is shown in Fig. 1.

3.2. Data extraction

The 10 articles are detailed in Table 1. The duration of the intervention (in weeks) was specified in seven articles: 4 [16], 6 [17], 8

[1] https://www.sforl.org/wp-content/uploads/2023/08/Texte-Reco-Place-de-la-reeducation-dans-la-prise-en-charge-des-vertiges-dorigine-vestibulaire-28-08-2023.pdf.

[2] https://www.has-sante.fr/.

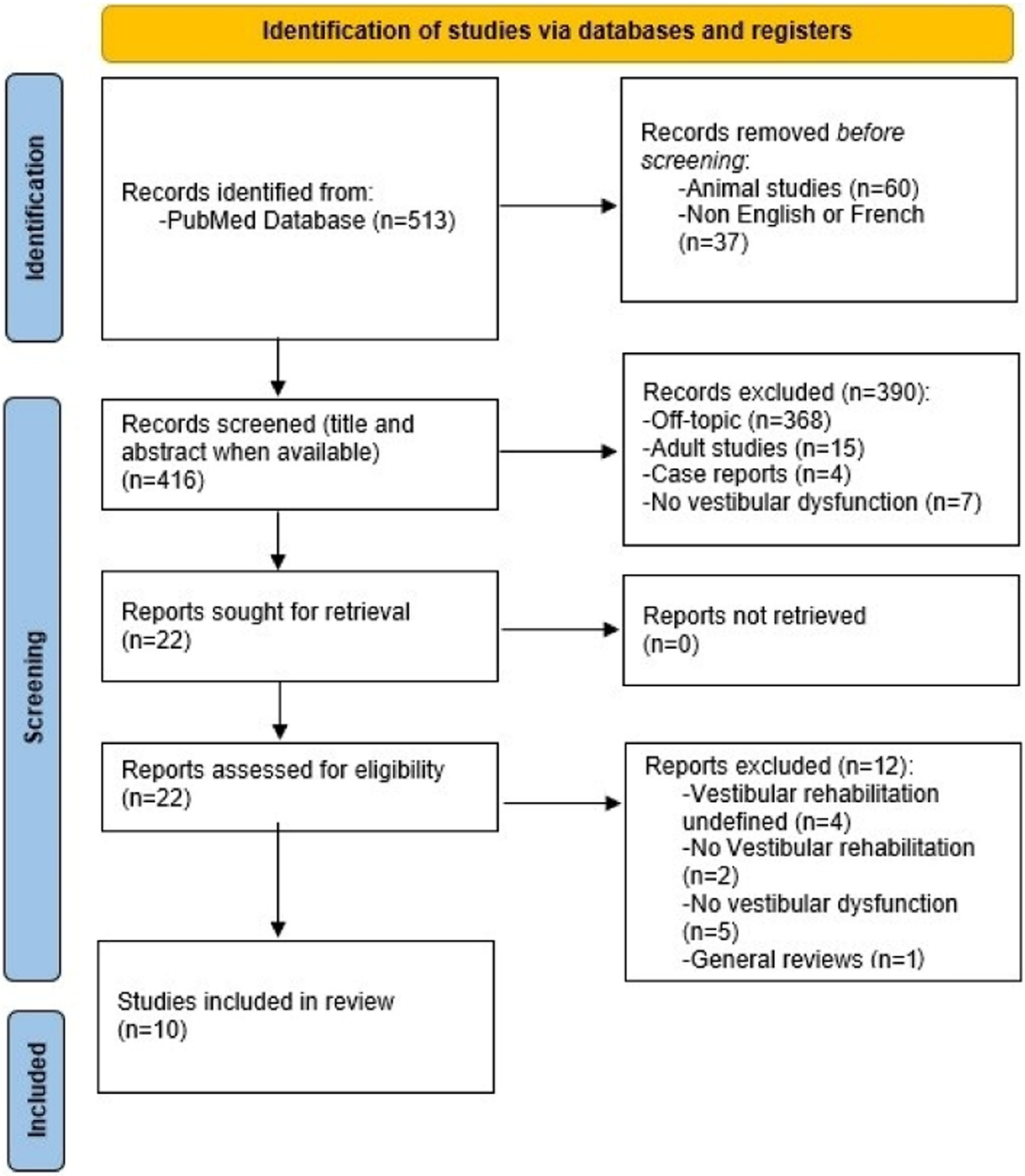

Fig. 1. Prisma flowchart.

[18,19], 10 [20], or 12 weeks [10,21]. The type of intervention (vestibular rehabilitation, VR) was well defined in all articles. VR consisted mainly of gaze stabilization exercises [17-20,22,23], balance exercises [10,18-21,22,23], and head–eye coordination [10,21,22]. Some studies added cervical spine physiotherapy [19] and somatosensory training [20].

3.3. Quality assessment of included studies

The critical appraisal of the studies is presented in Table 2. The studies concerned the use of VR in children with impaired vestibular function. Only three studies [10,17,24] defined the inclusion criteria appropriately: Either the vestibular impairment was not documented at all or it was poorly documented [16,18,20,22], or the study groups also included adult patients [19,23]. Two out of 10 studies were retrospective [22,23]; further, these studies presented general effects of VR rather than targeted interventions for patients with vestibular impairment. Blinding was applied in four studies [10,16,19,20]. The process of VR was clear in all studies. Missing data as well as participant dropout and withdrawal rates exceeded 10 % in five articles [17–19,21,22] and were not mentioned in one article [23].

4. Discussion

4.1. Pre-rehabilitation assessment in children

As hearing plays an important role in postural orientation and balance [25], the assessment systematically includes an age-appropriate hearing evaluation. Temporal bone densitometry with magnetic

Table 1
Studies included in the review.

References	Study design	Number of patients included	Parameters analyzed	Main results	Evidence level
Melo et al. 2019 [24]	Systematic review	153 children with SNHL and mostly vestibular dysfunction	Using VR programs to improve postural control, balance and/or gait.	Low quality of evidence observed. Authors suggested new trials on the topic	3
Rine et al. 2004 [34]	Randomized controlled	25 children	12 weeks VR: balance, coordination and gross motor skills	SG: motor development scores improvement (PDMS) ($p = 0.004$); improved postural control (not significant)	2
Ebrahimi et al. 2017 [18]	Randomized controlled	24 children	8 weeks VR: balance and gaze stabilization during head movements.	SG: significant improvement in postural control (dynamic posturography) ($p < 0.05$) CG: no significant improvement	2
Medeiros et al. 2005 [21]	Non-comparative interventional prospective	16 children	12 weeks VR: coordination, gaze stabilization, balance	SG: disappearance of dizziness and neurovegetative symptoms with improved postural control (dynamic posturography) ($p < 0.05$).	4
Schneider et al. 2014 [19]	Randomized controlled	29 teenagers with dizziness following cerebral concussion	8 weeks VR: habituation, adaptation exercises, gaze stabilization, balance	SG: 73 % improvement of symptoms CG: 7 %. 55 % more of SG than CG return to sport in 8 weeks ($p < 0.002$).	2
Storey et al. 2018 [22]	Retrospective cohort	109 children with concussion.	VR management. Assessment of symptoms, balance	80 %: reduction in dizziness; improvement in balance ($p < 0.0001$).	4
Alsalaheen et al. 2010 [23]	Retrospective chart review	67 children (mean 16 years) who suffered from concussion	VR to reduce vertigo and improve balance (using sensory organization test) and gaze stabilization.	Reduced vertigo ($p < 0.005$), improved walking and balance after concussion ($p < 0.025$).	4
Kontos et al. 2021 [16]	Randomized comparative controlled	55 teenagers with concussion with vestibular symptoms or impairment	4 weeks VR exercises for 30 min/day	SG: improvement of VOR ($p < 0.05$) compared to CG. Improvement in visual motion sensitivity (not significant).	2
Tramontano et al. 2017 [20]	Randomized comparative controlled	14 children with cerebral palsy.	10 weeks VR: (postural control exercises, gaze stabilization and multisensory integration.	SG: improvement in postural parameters, including the ability to stabilize the head and trunk in space during dynamic situations ($p = 0.003$).	2
Braswell and Rine 2006 [17]	Prospective preliminary study	2 children with SNHL and vestibular dysfunction	6 weeks gaze stabilization exercises	Improvement in the DVA clinical test score and reading acuity. Only 2 children included.	4

VR, vestibular rehabilitation; SG, study group; CG, control group; VOR, vestibulo-ocular reflex; DVA, dynamic visual acuity; PDMS, Peabody Developmental Motor Scales; SNHL, sensorineural hearing loss.

Table 2
Quality assessment.

Study	Confounding	Selection bias	Classification of intervention bias	Deviation from intended intervention	Missing data bias	Measurement of outcomes bias	Selection of reported results bias
Melo et al. [24]	Ø	NA	Ø	Ø	Ø	NA	Ø
Rine et al. [34]	○	○	Ø	Ø	○	○	○
Ebrahimi et al. [18]	Ø	○	○	Ø	Ø	⭘	Ø
Medeiros et al. [21]	●	●	Ø	●	○	⭘	○
Schneider et al. [19]	●	○	●	Ø	○	⭘	○
Storey et al. [22]	●	●	Ø	●	●	⭘	⭘
Alsalaheen et al. [23]	●	●	○	Ø	●	NA	⭘
Kontos et al. [16]	●	○	○	○	●	○	○
Tramontano et al. [20]	Ø	○	○	○	○	○	○
Braswell and Rine [17]	Ø	●	○	○	○	⭘	○

Confounding: ○ No confounding (aims and variables well defined), presence of confounders, no information. Selection of participants: ○ No bias in selection, ● Presence of bias, NA not applicable. Classification of intervention: ○ Absence of measurement bias, ● Presence of bias, Ø No information. Deviation from intended intervention: ○ Absence of performance bias, ● Presence of bias, Ø No information. Missing data: ○ <10 % missing data, ● ≥10 %, Ø No information. Measurement of outcomes: ○ Similar measurement of outcomes between groups and Blinding of assessors, ⭘ Similar measurement and no blinding, ● Difference of measurement and no blinding, NA not applicable. Selection of reported results: ○ Primary outcomes reported according to the protocol, ⭘ Selective report of a subgroup of participants with explanations, ● Missing outcomes/data reported for a subgroup, Ø no information.

resonance imaging (MRI) of the internal auditory canals (IACs) and brain is sometimes also indicated if there is any doubt about underlying neurological pathology or invasive pathology of the IACs.

Individuals with vestibular dysfunction have difficulties when postural reactions such as the hip strategy are needed [26]. Consequently, postural tasks involving single-leg standing or walking in tandem are usually less effective [27]. Timed single-leg stance tests showed good psychometric qualities from the age of 4 to 5 years; maintaining balance on each foot in eyes-open and eyes-closed conditions is compared with normative values [27]. The relative participation of each sensory system involved in postural control is studied on dynamic posturography platforms (without normative values for children) [28,29] or clinical tests such as the modified Clinical Test of Sensory Interaction on Balance (CTSIB-M) [30].

Motor and postural abilities could be assessed with standardized batteries, the DF-MOT scale (French scale, 0–4 years) [31], and the Movement Assessment Battery for Children – second edition (MABC-2, 3–16 years), with the MABC providing an overview of motor performance (manual dexterity, ball skills, and balance) [32].

The Video Head Impulse Test (VHIT) measures VOR gain at high speed and the compensation strategy in the event of an impairment. It can be used in early infancy, as early as 3 months of age [33]. Dynamic visual acuity (DVA) can be used from 4 years of age, with letters or optotypes, to assess more accurately the consequence of VOR impairment [34] or to monitor progress following gaze stabilization exercises during head movements. Partial or total loss of the vestibulospinal reflex will induce a lack or perturbation of postural adjustments [7–9]. When implementing rehabilitation treatment, substitution or adaptation principles could be used depending on the results of the otolithic assessment. However, the functional improvement of postural responses should be targeted, not the stimulation of the vestibulospinal reflex per se.

Box 1

It is recommended that a vestibular assessment be carried out before vestibular rehabilitation, including a study of postural control, vestibulo-ocular reflex (grade C), and otolithic function (expert opinion).

Box 2

It is recommended that children with bilateral vestibular impairment be treated using gaze stabilization exercises for adaptation and substitution (expert opinion).
In cases of congenital vestibular dysfunction, it is recommended from an early age to train different aspects of postural control, including anticipatory and postural reactions (expert opinion).
Vestibular rehabilitation is recommended for children whose vestibular dysfunction leads to functional disorders (balance, postural–motor level, vestibulo-ocular reflex deficiency or symptoms of vertigo) and should be adapted to the child's age (grade B).

4.2. Recommendation: indications and principles of vestibular rehabilitation for children with vestibular impairment

VR in children is adapted to the stage of postural–motor development. It should be personalized, active, early, and playful to ensure optimal compliance [1]. The aim is to use exercises either to improve vestibular function or to promote sensory substitution. It is very important for the parents of young children to be present and involved during the sessions, to highlight the functional objectives to be worked on, in order to continue the exercise program at home.

There are no articles on the efficacy of early VR management in children under 5 years of age with congenital vestibular dysfunction. By analogy with neuromotor rehabilitation of children with CP, for example, it may be assumed that early and specific rehabilitation treatment could maximize recovery [35]. Clinical experience and the literature show that VR treatment might benefit infants and young children with vestibular dysfunction and poor postural control (particularly in the presence of axial hypotonia). The preferred approach would be the one presented in the article by Tramontano et al., combining the principles of neuromotor rehabilitation and VR principles adapted to each child's age and functional level [20]. It involves enriched environmental exploration and active motor practice to promote postural development and motor learning.

In a small sample of two children with SNHL and bilateral vestibular dysfunction, Braswell and Rine (2006) analyzed the efficacy of gaze stabilization exercises in adaptation and substitution [17]. Both patients underwent 18 rehabilitation sessions three times a week. Following the intervention, there was an improvement in the DVA clinical test score and reading fluency [17]. Ebrahimi et al., in a randomized controlled trial, also demonstrated the value of VR in a larger sample of 24 patients [18]. VR included exercises to re-educate balance and stabilize gaze during head movements; rehabilitation took place over an 8-week period, three times a week. At the end of the intervention, the experimental group showed a significant improvement in postural stability according to dynamic posturography parameters compared with the control group. Rine et al. showed in a randomized controlled study of 25 children with SNHL and vestibular impairment that a 12-week course of treatment focusing on balance, eye–head and eye–hand coordination, and gross motor exercises helped to make up for delayed postural motor acquisition and to improve postural control [10]. The assessment was carried out using the standardized Peabody Developmental Motor Scales. Postural abilities were assessed using dynamic posturography [10]. A systematic review by Melo et al. examined six studies proposing a VR program to children with SNHL. The authors underlined the evidence that VR exercise programs could improve postural control, balance, and gait in this population. However, an important bias was the lack of control over the presence of vestibular dysfunction [24].

In the case of acute unilateral vestibular damage, VR aims at promoting vestibular compensation and thus improving postural control, reducing symptoms, and improving functioning during daily living. In a prospective, non-comparative interventional study, Medeiros et al. showed a reduction in vertiginous sensations and neurovegetative symptoms as well as improved postural control (on dynamic posturography) in a cohort of 16 children after treatment with VR. Rehabilitation took place over a 2-month period and focused on habituation exercises, stabilization of gaze during head movements, and balance exercises [21].

In the context of vertigo after a head injury, Schneider et al. conducted a randomized controlled trial rehabilitating a sample of 29 adolescents with persistent vertiginous sensations in the aftermath of a concussion [19]. Treatment included VR and cervical spine exercises. At 8 weeks after the start of treatment, 73 % of the participants in the trained group had a remission of symptoms, enabling them to return to sport, compared with only 7 % in the control group [19]. In a retrospective cohort study, Storey et al. analyzed the efficacy of VR in a population of 109 children with concussion [22]. At the end of rehabilitation, 80 % of patients showed a reduction in vertiginous symptoms as well as an improvement in balance and vestibulo-ocular function. Alsalaheen et al. studied the effect of VR on reducing vertigo and improving walking and balance in 114 patients, including 67 adolescents, who had suffered a concussion [23]. There was an improvement in vertigo and balance in the eyes-open or eyes-closed, fixed-support condition of the Sensory Organization Test. The authors conclude that VR can reduce vertigo and improve walking and balance after concussion; improvement was not age dependent. Building on these studies, Kontos et al. compared the efficacy of a 4-week precision VR intervention versus a behavioral management control intervention for 55 adolescents with concussion who were diagnosed with vestibular symptoms and/or dysfunction. After 4 weeks, the study group participants showed significantly improved VOR during the intervention period, but not visual motion sensitivity [23].

Whereas vestibular stimulation (which could have positive effects on the development of motor control) has never been tested as part of a therapeutic approach for children with CP, Tramontano et al. proposed a combination of 10 twice-weekly neuromotor and vestibular physiotherapy sessions in a group of 14 children with CP [20]. The aim was to improve postural control and gaze stabilization and to optimize multisensory integration. The results showed that such a combination brought a statistically significant improvement in certain postural parameters, including stabilizing the head and trunk in space during dynamic situations [20].

Finally, some studies have shown the value of VR [36] for treating visual vertigo in adult patients, a symptom corresponding to dizzy sensations triggered by a complex moving visual stimulus. It is caused by overreliance on visual information for perception and postural control and can be found in the aftermath of vestibular dysfunction, in migraine pathology, or after concussion. Patients with vestibular dysfunction, concussion, or migraine pathology can become highly sensitive to visual stimuli. Patients may develop vertigo and/or spatial disorientation triggered by a complex moving visual stimulus. In adults, one approach used to reduce this type of symptom is the use of optokinetic stimulation, either with a planetarium-type generator or with a virtual reality system [36]. To date, we are not aware of any publications analyzing such an approach in children or adolescents. It should be stressed that this type of exercise calls on sensory reweighting capacity, which takes a relatively long time to develop and reach adult-like levels [37]. In children, the difficulty lies in distinguishing between external information and postural adaptations induced by their own movement; this requires the presence of a sophisticated internal model enabling the sensory consequences of movement to be anticipated [37]. Consequently, it seems advisable not to use this type of stimulation in children and to use it cautiously in adolescents, pending recommendations for good practice or studies addressing this subject.

Box 3

Vestibular rehabilitation is recommended for children with head trauma—after ensuring that there is no neurological pathology contraindicating it—and persistent vertigo or balance disorders (grade B).
Optokinetic stimulation and virtual reality are not recommended for vestibular rehabilitation in children and young adolescents (expert opinion).

4.3. Systematic review discussion

The present study has certain limitations; some studies were mostly observational, and there was a wide heterogeneity of tools used and a small sample size. To date, few studies have been carried out on VR in children, and these often concern a variety of pathologies. This may preclude generalization of the results to a wider more heterogeneous population. We used only the PubMed database, and we focused on pediatric studies involving children with potential vestibular dysfunction. The vestibular assessment performed prior to patient inclusion was often incomplete or rather heterogeneous. We chose to include patients with CP [20] or concussion after head trauma [16,19,22,23]. As we have seen, VR has already been performed for these patients. Children with CP tend to have poor balance reactions and walking difficulties attributed to brain damage occurring around birth. In addition, abnormal visuo-spatial perception, difficulties in coupling eye and hand movements to reach objects, and difficulties in stabilizing the head even in a seated position have been described (see [38] for review). Few articles evaluate vestibular function in children with CP. It has been reported that children with CP sometimes have asymmetric cervical vestibular-evoked myogenic potentials (cVEMPs) with reduced amplitudes [39]. In the study by Almutairi et al., children with cerebral palsy showed impaired VOR cancellation, poor use of the vestibular system for postural control, and impaired subjective visual vertical and horizontal perception [40]. The authors of this study concluded that these disorders were related to deficiencies in the central vestibular and oculomotor neural networks rather than to peripheral vestibular dysfunction. According to Christy et al., the movement-related deficits suffered by children with CP could be due to a vestibular impairment or disruption of the central vestibular pathways, with poor perception of verticality, poor balance and head control, and an inability to control gaze during movement [38]. Therefore, the current data do not allow us to propose a systematic vestibular assessment for this population. Certain types of exercise, such as gaze stabilization and balance exercises, could benefit children with CP with central vestibular network damage, but more studies are needed. Concussion results in many symptoms (unsteadiness, dizziness, visual problems); a mixed peripheral and central vestibular picture is frequently evoked [38], but often with few objective vestibular tests. A vestibular impairment may exist due to a temporal bone trauma; there may even be a transient benign paroxysmal positional vertigo, which then requires conventional otolith repositioning maneuvers.

5. Conclusion

It is recommended that a vestibular assessment be carried out before VR, including a study of the VOR, otolithic function, and postural control. In cases of vestibular dysfunction, physiotherapy treatment is recommended from an early age to train different aspects of postural control, including anticipatory and reactive postural adjustments. VR adapted to the pediatric population is recommended for children whose vestibular dysfunction leads to functional disorders or symptoms of vertigo for those who have suffered head trauma. It is recommended that children with bilateral vestibular impairment be treated using gaze stabilization exercises for adaptation and substitution. Optokinetic stimulation and virtual reality are not recommended for children and young adolescents.

Declaration of competing interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Funding

The author(s) declare that no financial support was received for the research, authorship, and/or publication of this article.

Acknowledgments

The authors would like to thank the entire working group of the Guidelines of the French Society of Otorhinolaryngology and Head and Neck Surgery (SFORL), “The role of rehabilitation in the management of vestibular vertigo”: Dr. Pierre Bertholon, Mr. Éric Blin, Dr. Didier Bouccara, Dr. Christian Chabert, Prof. Anne Charpiot, Mr. Sébastien Doutreligne, Dr. Xavier Dubernard, Mr. Thomas Dujardin, Dr. Maya Elziere, Dr. Marie-José Fraysse, Prof. Caroline Froment,

Dr. Philippe Guillou, Dr. Charlotte Hautefort, Prof. Martin Hitier, Dr. Michel Kossowski, Mrs. Marie-Laure Laborie, Prof. Michel Lacour, Dr. Benoite Lassalle-Kinic, Mr. Gaël Le Perf, Dr. Elena Laura Lemaitre, Dr. Stéphanie Leplaideur, Dr. Carole Masgnaux, Dr. Laura Mechtouff, Dr. Emeline Michel, Prof. Thierry Mom, Prof. Cécile Parietti-Winkler, Dr. Cécile Nicolas-Puel, Prof. François Puisieux, Prof. Jean-Claude Quintyn, Dr. Edwin Regrain, Prof. Sébastien Schmerber, Dr. Christian Van Nechel, Dr. Alexandra Weckel.

References

[1] Rine RM. Vestibular rehabilitation for children. Semin Hear 2018;39:334–44.
[2] Li CM, Hoffman HJ, Ward BK, et al. Epidemiology of dizziness and balance problems in children in the united states: a population-based study. J Pediatr 2016;171:240–7.e1-3.
[3] Wiener-Vacher SR, Quarez J, Priol AL. Epidemiology of vestibular impairments in a pediatric population. Semin Hear 2018;39:229–42.
[4] Camet ML, Hayashi SS, Sinks BC, et al. Determining the prevalence of vestibular screening failures in pediatric cancer patients whose therapies include radiation to the head/neck and platin-based therapies: a pilot study. Pediatr Blood Cancer 2018;65:e26992.
[5] Cushing SL, Gordon KA, Rutka JA, et al. Vestibular end-organ dysfunction in children with sensorineural hearing loss and cochlear implants: an expanded cohort and etiologic assessment. Otol Neurotol 2013;34:422–8.
[6] Krause E, Louza JP, Wechtenbruch J, et al. Influence of cochlear implantation on peripheral vestibular receptor function. Otolaryngol Head Neck Surg 2010;142:809–13.
[7] Abadie V, Wiener-Vacher S, Morisseau-Durand MP, et al. Vestibular anomalies in CHARGE syndrome: investigations on and consequences for postural development. Eur J Pediatr 2000;159:569–74.
[8] Rine RM, Cornwall G, Gan K, et al. Evidence of progressive delay of motor development in children with sensorineural hearing loss and concurrent vestibular dysfunction. Percept Mot Skills 2000;90:1101–12.
[9] Horak FB, Shupert CL, Dietz V, et al. Vestibular and somatosensory contributions to responses to head and body displacements in stance. Exp Brain Res 1994;100:93–106.
[10] Rine RM, Braswell J, Fisher D, et al. Improvement of motor development and postural control following intervention in children with sensorineural hearing loss and vestibular impairment. Int J Pediatr Otorhinolaryngol 2004;68:1141–8.
[11] Lopez C. Making sense of the body: the role of vestibular signals. Multisens Res 2015;28:525–57.
[12] Nakul E, Dabard C, Toupet M, et al. Body-maps of emotions in bilateral vestibulopathy. J Neurol 2020;267(Suppl 1):104–8.
[13] Franco ES, Panhoca I. Vestibular function in children underperforming at school. Braz J Otorhinolaryngol 2008;74:815–25.
[14] Wiener-Vacher SR, Hamilton DA, Wiener SI. Vestibular activity and cognitive development in children: perspectives. Front Integr Neurosci 2013;7:92.
[15] Page MJ, McKenzie JE, Bossuyt PM, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. Syst Rev 2021;10:89.
[16] Kontos AP, Eagle SR, Mucha A, et al. A randomized controlled trial of precision vestibular rehabilitation in adolescents following concussion: preliminary findings. J Pediatr 2021;239:193–9.
[17] Braswell J, Rine RM. Preliminary evidence of improved gaze stability following exercise in two children with vestibular hypofunction. Int J Pediatr Otorhinolaryngol 2006;70:1967–73.
[18] Ebrahimi AA, Jamshidi AA, Movallali G, et al. The effect of vestibular rehabilitation therapy program on sensory organization of deaf children with bilateral vestibular dysfunction. Acta Med Iran 2017;55:683–9.
[19] Schneider KJ, Meeuwisse WH, Nettel-Aguirre A, et al. Cervicovestibular rehabilitation in sport-related concussion: a randomised controlled trial. Br J Sports Med 2014;48:1294–8.
[20] Tramontano M, Medici A, Iosa M, et al. The effect of vestibular stimulation on motor functions of children with cerebral palsy. Motor Control 2017;21:299–311.
[21] Medeiros IR, Bittar RS, Pedalini ME, et al. Vestibular rehabilitation therapy in children. Otol Neurotol 2005;26:699–703.
[22] Storey EP, Wiebe DJ, D'Alonzo BA, et al. Vestibular rehabilitation is associated with visuovestibular improvement in pediatric concussion. J Neurol Phys Ther 2018;42:134–41.
[23] Alsalaheen BA, Mucha A, Morris LO, et al. Vestibular rehabilitation for dizziness and balance disorders after concussion. J Neurol Phys Ther 2010;34:87–93.
[24] Melo RS, Lemos A, Paiva GS, et al. Vestibular rehabilitation exercises programs to improve the postural control, balance and gait of children with sensorineural hearing loss: a systematic review. Int J Pediatr Otorhinolaryngol 2019;127:109650.
[25] Zhong X, Yost WA. Relationship between postural stability and spatial hearing. J Am Acad Audiol 2013;24:782–8.
[26] Creath R, Kiemel T, Horak F, et al. The role of vestibular and somatosensory systems in intersegmental control of upright stance. J Vestib Res 2008;18:39–49.
[27] Oyewumi M, Wolter NE, Heon E, et al. Using balance function to screen for vestibular impairment in children with sensorineural hearing loss and cochlear implants. Otol Neurotol 2016;37:926–32.
[28] Wolter NE, Gordon KA, Campos J, et al. Impact of the sensory environment on balance in children with bilateral cochleovestibular loss. Hear Res 2021;400:108134.
[29] Goulème N, Debue M, Spruyt K, et al. Changes of spatial and temporal characteristics of dynamic postural control in children with typical neurodevelopment with age: results of a multicenter pediatric study. Int J Pediatr Otorhinolaryngol 2018;113:272–80.
[30] Christy JB, Payne J, Azuero A, et al. Reliability and diagnostic accuracy of clinical tests of vestibular function for children. Pediatr Phys Ther 2014;26:180–9.
[31] Vaivre-Douret L. Une nouvelle échelle française d'évaluation du développement moteur du jeune enfant (0-4 ans) : repères pour la clinique et la recherche. Devenir 2013;15:179–89.
[32] Brown T, Lalor A. The Movement Assessment Battery for Children—Second Edition (MABC-2): a review and critique. Phys Occup Ther Pediatr 2009;29:86–103.
[33] Wiener-Vacher SR, Wiener SI. Video head impulse tests with a remote camera system: normative values of semicircular canal vestibulo-ocular reflex gain in infants and children. Front Neurol 2017;8:434.
[34] Rine RM, Braswell J. A clinical test of dynamic visual acuity for children. Int J Pediatr Otorhinolaryngol 2003;67:1195–201.
[35] Novak I, Morgan C, Adde L, et al. Early, accurate diagnosis and early intervention in cerebral palsy: advances in diagnosis and treatment. JAMA Pediatr 2017;171:897–907.
[36] Pavlou M, Lingeswaran A, Davies RA, et al. Simulator based rehabilitation in refractory dizziness. J Neurol 2004;251:983–95.
[37] Bair WN, Kiemel T, Jeka JJ, et al. Development of multisensory reweighting for posture control in children. Exp Brain Res 2007;183:435–46.
[38] Christy JB. Considerations for testing and treating children with central vestibular impairments. Semin Hear 2018;39:321–33.
[39] Akbarfahimi NHS, Rassafiani M, Rezazadeh N, et al. Assessment of the saccular function in children with spastic cerebral palsy. Neurophysiol 2016;48:9.
[40] Almutairi A, Cochrane GD, Christy JB. Vestibular and oculomotor function in children with CP: descriptive study. Int J Pediatr Otorhinolaryngol 2019;119:15–21.