Case Report

Vestibular Rehabilitation After Traumatic Brain Injury: Case Series

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Background and Purpose. There has been an increasing focus on vestibular rehabilitation (VR) after traumatic brain injury (TBI) in recent years. However, detailed descriptions of the content of and patient responses to VR after TBI are limited. The purposes of this case series are (1) to describe a modified, group-based VR intervention and (2) to examine changes in self-reported and performance-based outcome measures.

Case Description. Two women and 2 men (aged 24–45 years) with mild TBI, dizziness, and balance problems participated in an 8-week intervention consisting of group sessions with guidance, individually modified VR exercises, a home exercise program, and an exercise diary. Self-reported and performance-based outcome measures were applied to assess the impact of dizziness and balance problems on functions related to activity and participation.

Outcomes. The intervention caused no adverse effects. Three of the 4 patients reported reduced self-perceived disability because of dizziness, diminished frequency and severity of dizziness, improved health-related quality of life, reduced psychological distress, and improved performance-based balance. The change scores exceeded the minimal detectable change, indicating a clinically significant change or improvement in the direction of age-related norms. The fourth patient did not change or improve in most outcome measures.

Discussion. A modified, group-based VR intervention was safe and appeared to be viable and beneficial when addressing dizziness and balance problems after TBI. However, concurrent physical and psychological symptoms, other neurological deficits, and musculoskeletal problems might influence the course of central nervous system compensation and recovery. The present case series may be useful for tailoring VR interventions to patients with TBI. Future randomized controlled trials are warranted to evaluate the short- and long-term effects of VR after TBI.

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Patients with traumatic brain injury (TBI) commonly report dizziness and balance problems, with a prevalence of 23% to 81%.[1–4] Dizziness and balance problems are considered to be adverse prognostic factors after TBI that might cause functional limitations and psychological distress and might have a negative impact on quality of life and the ability to return to work.[5]

The underlying mechanisms of dizziness and balance problems after TBI are complex. Trauma might affect the labyrinth and other vestibular structures and cause benign paroxysmal positional vertigo (BPPV), labyrinthine concussion, perilymphatic fistula, and unilateral vestibular loss.[1,6] Dizziness without labyrinthine dysfunctions might indicate central posttraumatic vertigo, postconcussion syndrome, posttraumatic migraines, diffuse axonal injury, or anxiety-associated dizziness.[1,6] The traumatic mechanism that caused a possible vestibular injury, postconcussion symptoms, and other neurological or musculoskeletal symptoms concurrently characterizes the patient with TBI.[1,4,7]

Reports from studies applying principles of vestibular rehabilitation (VR) in patients with TBI indicate a reduction in dizziness and balance problems.[3,8–10] Modifications appear necessary to accommodate postconcussion symptoms and physical and cognitive problems after the trauma.[2,7,11] However, descriptions of VR programs for patients with TBI are limited, and a preliminary search for randomized controlled trials (RCTs) to establish the effect of VR on patients with TBI did not render any results. Explorations such as in case studies that illuminate how VR can be modified in clinical practice might stimulate clinicians and researchers to quantify the effects of VR in patients with dizziness and balance problems after TBI.

We modified a group-based VR intervention originally developed for patients with chronic dizziness at Oslo and Akershus University College.[12] The modifications included a follow-up twice weekly for 8 weeks, with an emphasis on individual modifications and progression of the intervention with considerations of other postconcussion symptoms and typical challenges after TBI. The program was mainly based on the motor control theory[13] and the theory of positive psychology for coping with the symptom pressure and disease burden.[14] The VR intervention used motor learning principles, with gradual increase in challenges of balance ability that required integration of multiple sensory inputs. Elements from established VR programs were included and followed the principles of habituation, adaptation, and substitution exercises and balance relearning.[1,2,7,11,13]

The primary aim of this case series is to describe a group-based VR intervention for patients with TBI. The secondary aim is to examine how the intervention may assist in addressing the targeted problems of dizziness and balance problems, by describing changes in self-perceived dizziness, balance, and health-related quality of life (HRQL). The intervention was applied in an ongoing RCT (ClinicalTrials.gov identifier: NCT01695577).

Case Descriptions: Patient History and Systems Review

Four patients were recruited at an outpatient clinic at the Department of Physical Medicine and Rehabilitation at Oslo University Hospital. They were the first 2 male and female patients recruited for this case series prior to the ongoing RCT. Inclusion criteria were TBI, age between 16 and 60 years, dizziness reported on the Rivermead Postconcussion Symptoms Questionnaire (RPQ),[15] or a positive Romberg test. Patients were excluded if they had severe psychological disease, language problems, cognitive dysfunction, fractures, or other comorbidities affecting mobility and independent gait. Written informed consent was obtained from the patients.

The patients underwent a medical evaluation by a physiatrist. A physical therapist (I.K.) assessed the patients with the modified Clinical Test for Sensory Interaction in Balance (mCTSIB), single-leg stance, tests of the oculomotor system (smooth pursuit, saccadic eye movements), head-thrust test, clinical Dynamic Visual Acuity Test (DVAT), and positional testing (Dix-Hallpike test and Roll test), all of which are commonly applied clinical tests in patients with dizziness.[1] Patient data are presented in Table 1.

Clinical Impression 1

The patients had mild TBI according to the Glasgow Coma Scale (GCS) score and persistent dizziness and were diagnosed with postconcussion syndrome by the physiatrist using the *International Statistical Classification of Diseases and Related Health Problems*, 10th revision (ICD-10) criteria.[1]

The patients were on sick leave or had delayed their studies at college or university due to the TBI. They had persistent symptoms in the physical, cognitive, and psychological/emotional domains of the RPQ. The results from the tests performed by the physical therapist are presented in Table 1. The tests showed mild balance problems, especially with eyes closed, which may indicate visual dependency for balance, and difficulties with sensory integration. The oculomotor tests were normal but symptomatic (dizziness, eye strain) in all patients. The DVAT provoked dizziness during or right after the test and was positive (≥4 lines difference) in patient 2, indicating reduced vestibulo-ocular reflex (VOR). Patient 3 tested positive for both posterior semicircular canal (PSC) and horizontal semicircular canal (HSC) BPPV. All patients reported dizziness provoked by movements of the head or body or by watching moving visual objects (traffic, crowds of people, movies, television), indicating motion sensitivity. Head-thrust tests were negative in all patients. Patients 1 and 4 reported neck pain and decreased active range of motion (AROM), indicating a possible cervicogenic disorder. Patient 4 had a positive computed tomography scan (intraventricular hemorrhage) that indicated possible central posttraumatic vertigo.

The patients were considered relevant candidates for the modified VR intervention program. They had each received a multidisciplinary evaluation and rehabilitation at Oslo University Hospital but had not participated in a VR program prior to inclusion in this study.

Table 1.
Demographic and Injury-Related Characteristics: Baseline Status, Symptoms, and Clinical Assessments[a]

Variable	Patient 1	Patient 2	Patient 3	Patient 4
Sex/age	Male/34 y	Male/25 y	Female/40 y	Female/45 y
Educational level	College or university	College or university	College or university	College or university
GCS score	15	14	15	15
PTA/LOC	Yes/yes	No/no	No/no	Yes/no
CT/MRI	Negative/negative	Negative/negative	Negative/negative	Positive[b]/negative
Cause of injury	Traffic accident	Violence	Fall	Fall
Time since injury	18 mo	30 mo	9 mo	10 mo
Sick leave/study status	50% sick leave	Reduced number of college courses	40% sick leave	80% sick leave
Comorbidities	None	None	Low back pain, bradycardia	Cardiovascular and metabolic dysfunctions
Medication	Painkillers	Painkillers	Painkillers	Painkillers, medications for comorbidities
Main symptoms reported on the RPQ in order of severity	Dizziness, nausea, light sensitivity, headache, fatigue, noise sensitivity, sleep disturbance, blurred vision, feeling frustrated, poor concentration	Fatigue, dizziness, noise sensitivity, feeling depressed, forgetfulness, poor concentration, light sensitivity, headache, blurred vision, feeling frustrated	Dizziness, noise sensitivity, fatigue, forgetfulness, poor concentration, taking longer to think, headache, nausea, sleep disturbance, feeling frustrated	Fatigue, noise sensitivity, feeling depressed, forgetfulness, poor concentration, taking longer to think, headache, sleep disturbance, feeling frustrated, dizziness
mCTSIB	Normal	Increased sway EC on foam surface	Increased sway backward and to the right EC on both firm and foam surface	Increased sway EC on firm and foam surface
Tandem/single-leg stance	Increased sway/reduced on left leg, EC compared with right	Increased sway/reduced on both legs, EC	Increased sway/reduced on right leg, EC	Increased sway/reduced on both legs, EC
Oculomotor tests	Normal but symptomatic, eye strain, nausea, forehead pressure	Normal but symptomatic, eye strain	Normal but symptomatic, eye strain right eye, dizzy	Normal but symptomatic, dizzy, eye strain
Head thrust test	Negative	Negative	Negative	Negative
cDVAT with an eye chart[c]	Negative	Positive (≥4 lines difference)	Negative	Negative
Positional testing: Dix-Hallpike test, roll test	Negative	Negative	Positive for right posterior and horizontal semicircular canal	Negative
Neck pain/AROM	Neck pain/reduced AROM	Normal	Normal	Neck pain/reduced AROM

[a] GCS=Glasgow Coma Scale, PTA=posttraumatic amnesia, LOC=loss of consciousness, CT=computerized tomography, MRI=magnetic resonance imaging, RPQ=Rivermead Postconcussion Symptoms Questionnaire, EC=eyes closed, mCTSIB=modified Clinical Test of Sensory Interaction in Balance, cDVAT=clinical Dynamic Visual Acuity Test, AROM=active range of motion.
[b] Computed tomographic scan showed intraventricular hemorrhage. Glasgow Coma Scale score, PTA, and LOC registered at admittance to the hospital. Computed tomographic scan taken at admittance to the hospital.
[c] Logarithmic Visual Acuity Chart (ETDRS format) with notations for testing at 2 m (6.5 ft). Chart R and chart 2 (using logMAR as measurement) (Precision Vision, 944 First St, La Salle, IL 61301).

Examination

Standardized self-reported and performance-based instruments measuring self-perceived handicap, dizziness, balance, mobility, and HRQL were used to evaluate patient outcomes. The overview of the outcome measures, including their psychometric properties, is presented in Table 2. The same physical therapist (I.K.) carried out the assessments on each patient before and after the intervention.

Self-reported Outcome Measures

Self-perceived disability because of dizziness was measured with the Dizziness Handicap Inventory (DHI).[16] The frequency and severity of dizziness symptoms in the preceding month were mea-

Table 2.
Standardized Outcome Measures[a]

Outcome Measure	ICF Domain	Items, Scale, Range	Psychometric Properties
DHI[b]	Impairment Activity Participation	25 items, 3 response levels (yes=4, sometimes=2, no=0), range=0–100 (best–worst)	Satisfactory reliability (ICC [1,1]=.90), internal consistency (Cronbach alpha=.88–.95), MIC=11 points, SDD=20 points[16] Mild disability=0–30 points, moderate disability=31–60 points, severe disability=61–100 points
VSS-SF	Impairment Activity	15 items, 5 point ordinal scale (0 [never]–4 [very often]), range=0–60 (best–worst)	Satisfactory reliability (ICC=.88),[17] clinically significant change ≥3 points, severe dizziness ≥12 points[17,18]
RPQ (RPQ-3=physical subscale, RPQ-13=psychological subscale)	Impairment	16 items, 5-point ordinal scale (0 [no problem]–4 [severe problem]), RPQ-3: range=0–12 (best–worst), RPQ-13: range=0–52 (best–worst)	RPQ-13 and RPQ-3 test-retest reliability (nonparametric correlation coefficients=.89 and .72, respectively) ($P<.01$). Validated for the TBI population; positive correlations with Rivermead Head Injury Follow-up Questionnaire=.83 and .62, respectively ($P<.01$).[15]
QOLIBRI[b]	Participation	37 items, 5-point ordinal scale (1 ["not at all satisfied"]–5 [very satisfied]), range=0–100 (worst–best); 6 subscales (cognition, self, daily life and autonomy, social life, emotions, physical problems)	Good test-retest reliability and internal consistency. Satisfactory construct and content validity.[19,20]
HADS[b]	Impairment Activity	14 items, 4-point ordinal scale (0 ["not at all"]–3 ["yes, definitely"]), range=0–42 (best–worst)	Validated for patients with TBI.[22] Scores 15–18=possible cases of psychological distress, scores ≥19=significant psychological distress requiring treatment.[21,22]
BESS[b]	Impairment	6 items, maximum of 10 errors for each item, range=0–60 (best–worst)	Moderate-to-good reliability (intratester ICC=.60–.92, intertester ICC=.57–.85). Moderate-to-high criterion-related validity. High content validity.[23] Interrater/intrarater MDC=9.4/7.3.[24]
HiMAT[b]	Impairment Activity	13 items, 5-point (0–4) and 6-point (0–5) ordinal scales, range=0–54 (worst–best)	Interrater and intrarater reliability (interrater ICC=.99, intrarater ICC=.95). Criterion validity was acceptable ($r=-.63$, $P<.001$). MDC=−3 to +4 points. Good responsiveness (AUC=0.86).[25]

[a] DHI=Dizziness Handicap Inventory, VSS-SF=Vertigo Symptom Scale–Short Form, RPQ=Rivermead Postconcussion Symptoms Questionnaire, QOLIBRI=Quality of Life After Traumatic Brain Injury, HADS=Hospital Anxiety and Depression Scale, BESS=Balance Error Reporting System, HiMAT=High-Level Mobility Assessment Tool for Traumatic Brain Injury, ICC=intraclass correlation coefficient, MIC=minimal important change, SDD=smallest detectable difference, MDC=minimal detectable change, TBI=traumatic brain injury, AUC=area under curve.
[b] Outcome measures reviewed in the Rehabilitation Measures Database (http://www.rehabmeasures.org).

sured using the Vertigo Symptom Scale–Short Form (VSS-SF). The VSS-SF comprises 2 subscales: vertigo-balance (VSS-V) and autonomic anxiety symptoms (VSS-A).[17,18] Postconcussion symptoms were measured with the RPQ. The RPQ comprises 2 subscales: physical (RPQ-3) and psychological (RPQ-13).[15] Health-related quality of life was measured with the Quality of Life After Brain Injury (QOLIBRI), a self-report instrument with 6 subscales that provides a profile of functioning and a total score for HRQL.[19,20] Psychological distress was assessed with the Hospital Anxiety and Depression Scale (HADS).[21,22]

Performance Based Outcome Measures

Balance was assessed with the Balance Error Scoring System (BESS), a standardized balance testing system consisting of three 20-second stances with eyes closed (double-leg stance, single-leg stance, and tandem stance) on firm and foam surfaces.[23,24]

Table 3.
Preintervention (Pre) and Postintervention (Post) Scores and Change Scores in Outcome Measures: Tentative Underlying Cause of Dizziness and Balance Problems and Number of Sessions Attended[a]

	Patient 1			Patient 2			Patient 3			Patient 4		
Outcome Measure	**Pre**	**Post**	**Change**	**Pre**	**Post**	**Change**	**Pre**	**Post**	**Change**	**Pre**	**Post**	**Change**
DHI	48	26	**−22**	56	2	**−54**	74	54	**−20**	48	46	−2
VSS-SF	19	10	**−9**	19	0	**−19**	42	37	**−5**	17	20	+3
VSS-V	13	6	**−7**	12	0	**−12**	31	25	**−6**	3	5	+2
VSS-A	6	4	−2	7	0	**−7**	11	12	+1	14	15	+1
RPQ-3	9	2	−7	5	0	−5	10	10	0	5	5	0
RPQ-13	13	12	−1	27	4	−23	36	24	−12	40	28	−12
QOLIBRI	40	43	+3	41	67	**+26**	38	68	**+30**	43	54	+11
HADS	20	14	−6	20	10	−10	19	11	−8	20	23	+3
BESS	33	18	**−14**	34	12	**−22**	29	11	**−18**	30	25	−5
HiMAT	53	53	0	46	54	**+8**	39	40	+1			
Tentative underlying cause of dizziness/ balance problems	Motion sensitivity, possible cervicogenic disorder			Vestibular hypofunction, reduced vestibulo-ocular reflex			BPPV, motion sensitivity and reduced sensory integration			Reduced sensory integration and central posttraumatic vertigo		
Sessions attended	9/16			8/16			13/16			15/16		

[a] DHI=Dizziness Handicap Inventory, VSS-SF=Vertigo Symptom Scale–Short Form sum score, VSS-V=vertigo-balance subscale of the VSS-SF, VSS-A=autonomic anxiety symptoms subscale of the VSS-SF, RPQ-3=physical subscale of the Rivermead Postconcussion Symptoms Questionnaire, RPQ-13=psychological subscale of the Rivermead Postconcussion Symptoms Questionnaire, QOLIBRI=Quality Of Life After Traumatic Brain Injury, HADS=Hospital Anxiety and Depression Scale, BESS=Balance Error Scoring System, HiMAT=High-Level Mobility Assessment Tool for Traumatic Brain Injury, BPPV=benign paroxysmal positional vertigo. Change scores exceeding known smallest detectable change, minimal detectable change, or minimal important change are shown in bold font.

Mobility was measured with the High-Level Mobility Assessment Tool for traumatic brain injury (HiMAT). The HiMAT consists of walking, running, skipping, hopping, and stair items measured with a stopwatch or tape measure.[25]

Clinical Impression 2

The patients reported moderate-to-severe disabilities because of dizziness (DHI) and severe dizziness (VSS-SF) (Tab. 3). Postconcussion symptoms were reported in both subscales of the RPQ. The QOLIBRI sum score indicated a lower HRQL than for a reference group.[19] The patients also reported some degree of psychological distress (HADS). Balance measured with the BESS test showed scores below-normal data and confirmed the visual dependency pattern and reduced sensory integration observed in the initial assessments of balance. Scores of mobility (HiMAT) showed 1 patient within the normal range and 2 patients with slightly reduced pace and increased symptoms of dizziness during testing. One patient did not perform the test due to painful feet.

The standardized self-reported and performance-based outcome measures confirmed that the patients had disabilities comprising impairments and reduced activity and participation commonly observed in the TBI population. Based on the clinical assessments and the standardized outcome measures, a tentative underlying cause of dizziness and balance problems was identified (Tab. 3). To indicate improvements, we expected that changes in the outcome measures would exceed measurement error, improve in age-related norms, and indicate a clinically significant change.

Intervention

The modified, group-based VR intervention aimed to decrease dizziness and motion sensitivity and improve gaze stability, functional balance, general activity levels, and the patient's HRQL. The intervention consisted of group sessions with guidance and individually modified VR exercises, a home exercise program (HEP), and an exercise diary (eAppendix 1, available at ptjournal.apta.org). Two physical therapists experienced in vestibular and TBI rehabilitation were responsible for the intervention twice weekly for 8 weeks. The groups included 2 to 5 patients. The 2 weekly group sessions differed (Tab. 4). For both sessions, the VR exercises were individually modified. The circle training design in session 1 had stations that allowed patients to work individually, allowing them to skip stations they could not tolerate or did not need. In session 2, we focused more on general exercises for muscle conditioning and strengthening, and interactions between group members were stimulated by working in pairs and using balls and balloons for habituation and balancing tasks and exercises. The rationale for the exercises and examples of how the exercises were performed are shown in eAppendix 2.

The individual tailoring of exercises performed during the group sessions and in the HEP was based on symptoms, signs, and functional challenges at each patient's baseline and on the tentative underlying cause of their dizziness. The exercises typically comprised Brandt-Daroff exercises and maneuver treatment (Epley and Bar-B-Que Roll maneu-

Table 4.
Overview of Modified Vestibular Rehabilitation Intervention Program for Patients With Traumatic Brain Injury

Category	Intervention Content Day 1; 90-Min Session	Intervention Content Day 2; 60-Min Session
Location	A therapy room at Oslo and Akershus University College	A gymnasium at Oslo and Akershus University College
Guidance	Information, confidence building, education, and reorientation, 30 min	
Warm-up phase	10–15 min with stationary bike, treadmill, or elliptical trainer	Walking with different modifications: on toes, bending down, turning, walking in different directions, turning head, and so on. Walking on different surfaces (eg, mats), jumping, running. Standing exercises with elements of coordination and rhythm.
Balance exercises	Circle training with different balancing tasks: sitting on a big ball/Airex (Airex AG, Sin, Switzerland) mat, weight shifting, bouncing, turning head, standing on rocker boards, Airex mat, trampolines, Bosu ball (BOSU Official Global Headquarters, Ashland, OH), walking with head and body turns, start and stops, picking up objects from the floor, catching/throwing beanbags, figure 8, obstacle course, badminton with balloons, dual tasks	Squatting, lunges in different directions. Standing in different positions with different tasks with eyes open/closed: feet together, semi-tandem, tandem, one leg, standing on Airex mats. Working with weight shifting, stability limits. Walking in place, stepping in different directions and up/down on a step, balloons and ball exercises. Walking in different directions, walking with head and body turns, walking on unstable surfaces (mats).
Adaptation exercises for gaze stability[a]	X1: working most on far targets (2–3 m away) X2: viewing paradigm, target held in hand	X1: working most on near targets held in hand X2: viewing paradigm, target held in hand
Substitution exercises for gaze stability[a]	Active eye-head movement between 2 targets Remembered target exercise	Active eye-head movement between 2 targets. Remembered target exercise.
Substitution exercises for balance	Exercises with and without visual cues: standing balance with eyes open and closed, walking with and without visual fixation on objects Exercises with altered somatosensory cues: using sensory ball for enhancing proprioception, standing on foam	Standing and walking exercises with and without visual cues and altered somatosensory cues
Habituation exercises	Brandt-Daroff exercises, sitting or standing exercises with head tipped to knee, head turns, head pitches, standing whole-body turns, walking with head and body turns	Standing and walking exercises using different-sized balls, balloons; working in pairs using balls, balloons, “pair dance” with whole-body turns, whole-body rotations and flexion-extension
Relaxation	5–10 min Jacobson’s progressive muscle relaxation	5–10 min Jacobson’s progressive muscle relaxation
Home exercise program	2–5 individually adjusted exercises to be done daily Exercise program: walking, biking, swimming	
Exercise diary	Reviewed	

[a] Exercises are described in: Herdman SJ, Whitney SL. Physical therapy treatment of vestibular hypofunction. In: Herdman SJ, Clendaniel RA, eds. *Vestibular Rehabilitation*. 4th ed. Philadelphia, PA: FA Davis Co; 2014:398–399.

vers[1]) for BPPV (patient 3), habituation exercises for motion sensitivity and central posttraumatic vertigo (patients 1 and 4), adaptation exercises for symptoms exhibited during eye-head coordination and reduced VOR (patient 2), and exercises for reduced balance focusing on improving sensory integration (all patients). The HEP was given at the beginning of the intervention and included 2 to 5 exercises. Additionally, the patients were encouraged to engage in physical activities that they tolerated, such as walking, swimming, or biking. The exercise diary was used to enhance awareness and motivation and to register the performed exercises and activities and the patients’ responses to them. It was reviewed every week by the therapists.

Guidance sessions led by the physical therapists were held at the beginning of session 1. The guidance sessions were based on the patients' experiences, reflections, and active participation. The psychological aspect of recovery was promoted by information, confidence building, education, and reorientation. Furthermore, peer support was encouraged, and the group members shared experiences and provided emotional and practical support to each other. Increased self-efficacy was facilitated through a focus on positive experiences, gaining control by interpretation of physical and emotional symptoms, and strengthening the patients' beliefs in their own ability to reach their goals.[14] The guidance sessions also were used to review the exercise diaries and discuss questions regarding goal setting, progression, and the HEP.

The parameters (intensity, frequency, duration) of the VR exercises were determined by the patients' subjective symptom level (headache, dizziness, fatigue). Feedback from each patient during the group sessions and the exercise diary was used to determine the parameters of the exercises throughout the intervention period. We practiced a conservative approach with a careful, gradual introduction to the exercises to avoid a prolonged increase of symptoms and a delayed response to treatment. If tolerated, the exercises were increased if symptoms increased the exercises, and activities were modified according to the symptom level.[1,7] Resolution of increased symptoms within 15 to 30 minutes after the exercise session was used as a general guideline for modification and progression of the exercises.[1] The symptoms were monitored by the patients' exercise diary descriptions of physical and psychological reactions to the exercises. Examples of progression and modifications are shown in Tables 5 and 6.

Outcome

The patients attended 8 to 15 sessions. Although none of the patients attended the maximum number of 16 (twice weekly for 8 weeks) sessions, they appeared motivated and positive. The patients worked with their HEP and reported gradually increased activity levels. There were no adverse effects, although some increase in symptoms was noted by all 4 patients during the first weeks of the intervention. Patients 1 and 2 tolerated a faster progression of the exercises than did patients 3 and 4.

Results from the standardized outcome measures are presented in Table 3. Perceived disability because of dizziness (DHI) changed from moderate disability to mild disability in patients 1 and 2 and from severe disability to moderate disability in patient 3 (>minimal important change).[16] Patient 4's scores remained unchanged. Self-reported dizziness (VVS-SF) improved (>clinically significant change) for all but one patient (patient 4).[18] Improvements were mainly observed on the vertigo balance subscale (VSS-V). Patients 3 and 4 still reported scores above the cutoff of ≥12 points on the VVS-SF, indicating severe dizziness.[17] Postconcussion symptoms (RPQ) improved mainly on the physical subscale (RPQ-3) in patients 1 and 2, whereas patients 3 and 4 improved mainly on the psychological subscale (RPQ-13).

Health-related quality of life (QOLIBRI) improved in patients 2 and 3 from a score of approximately 40 to a score above 60. This finding was supported by measures on the HADS, which improved in all but one patient (patient 4), who showed a change to below the recommended cutoff point for possible psychological distress.[21] The BESS test for standing balance indicated improvement (>minimal detectable change [MDC])[24] in all but one patient (patient 4). Mobility and balance measured with the HiMAT showed that patient 2 improved by 8 points (>MDC),[25] whereas patients 1 and 3 showed the same pretest and posttest mobility scores.

Discussion

The primary aim of this case series is to describe a group-based VR intervention for patients with TBI, as such descriptions are limited. The secondary aim is to indicate how the intervention may assist in addressing dizziness and balance problems by describing changes in self-perceived dizziness, balance, and HRQL.

The described intervention drew on the possible advantages of both group-based and individual approaches. The group-based approach benefited from interactive and social processes.[14] It provided the patients with opportunities for indirect learning and peer support in addition to support, feedback, and information from the physical therapists.[14] The patients identified common challenges (TBI, dizziness) and explored ways of coping with their situation, which yielded positive social relationships and increased motivation for physical activities.[14] Moreover, the group-based approach was a favorable, less time-consuming approach that allowed therapists to treat several patients simultaneously. All patients in the present case series had mild TBI with different tentative underlying causes of their dizziness that were individually addressed during the intervention period. Improvements were shown in self-perceived dizziness, balance, and HRQL in 3 out of 4 patients, and there were no reports of adverse effects.

"Dizziness" is a nonspecific term that includes diffuse symptoms of disorientation and light-headedness, as well as more clear symptoms of vertigo and balance problems.[4] Dizziness is subjective and difficult both for patients to describe and for clinicians to interpret. Hence, there have been several attempts to classify or categorize dizziness after TBI to simplify diagnostic information and guide therapeutic decision making.[10,26] However, it may still be difficult to determine the underlying cause of dizziness. There may be overlap among categories of dizziness, and multiple causes of dizziness or vestibular dysfunction are found in 46% of patients after TBI.[26,27] We did not have data on any vestibular function testing performed by ear-nose-throat specialists; therefore, specific vestibular diagnoses were not confirmed in our patients. However, based on the clinical assessment, they all appeared to have multiple causes for their dizziness or balance problems. In addition, the selection criteria for this case series were more

Table 5.
Elements in Systematic Progression of Exercises and General Parameters for the Intervention: Intensity, Frequency, and Duration for the Respective Exercise Categories

Exercises	Progression	Intensity, Frequency, and Duration
Balance exercises	Posture: sitting, standing, walking, jumping, running Base of support: feet apart, feet together, semi-tandem, tandem, one foot Surface: level, mats, foam, Bosu balls (BOSU Official Global Headquarters, Ashland, OH), trampolines, wedges, wobble boards, obstacles, stairs Arm position: away from body, close to body, crossed over chest, hands on hips, reaching, picking up objects, juggling Head movement: still, nodding, rotating Visual input: eyes closed, eyes open, complex patterns, visually quiet environment, visually busy environment Cognitive dual task: secondary motor and cognitive tasks	Intensity: exercises must challenge the patient's balance Frequency: 2–3 times a day Duration of standing balance: 30 s $\times$ 2 repetitions Duration of dynamic balance: 1–5 min
Adaptation and substitution exercises for gaze stability	Posture: sitting, standing, walking Base of support: feet apart, feet together, semi-tandem, tandem, one foot Surface: level, mats, foam Visual input: visually quiet background, visually complex patterns: checkerboards X1 before X2, near before far targets, horizontal and vertical movements Subjective increase in tempo and range of motion (a metronome could be used to keep track of the increase in tempo)	Intensity: as fast as the patient can as long as the object stays in focus Frequency: 2–3 times a day Rest between movements until the symptoms subside before the next repetition Duration: the exercises are done until they trigger symptoms (dizziness, nausea, foggy vision), 15 s–2 min
Habituation exercises	Posture: sitting, standing, walking, Surface: level, mats, foam Subjective increase in tempo and range of motion	Intensity: exercise must provoke dizziness mildly to moderately Frequency: 25 times, 2–3 times a day Rest between movements until the symptoms subside before the next repetition Duration: approximately 5 min for one exercise
Home exercises Aerobic exercise program, progressive walking, or other activities	2–5 exercises from Tab. 4, depending on the patient's main problem progressively made more difficult Start with 2 exercises, progress to 3 or 4 exercises, gradually increase intensity, duration, and frequency as tolerated by the patient Aerobic exercise program: 15–20 min and gradually increasing activity, such as walking, Nordic walking, stair climbing, biking, skiing, hiking, and swimming. Intensity registered with Borg Rating of Perceived Exertion (RPE) Scale.	Intensity: as tolerated, registered by Borg RPE Scale A level between 11 and 15 on Borg RPE Scale was encouraged Frequency: 3–5 times a week Duration: 15–60 min

symptom based, targeting deficits in function rather than specific diagnoses.

In a case series such as this, it is difficult to determine whether the observed improvements in outcomes are results of the intervention or due to other factors, such as natural recovery, participation in other treatments, or impact of greater attention from the therapists. However, different aspects of the intervention were designed to increase function and decrease symptoms, which were reported in 3 out of 4 patients in self-perceived disability because of dizziness (DHI) and frequency and severity of dizziness (VSS-SF). Motion sensitivity that was reported by all patients could be due to sensory conflicts or a mismatch among the visual, vestibular, and somatosensory systems, which is commonly observed after TBI.[3] The intervention addressed symptoms of motion sensitivity by habituation that aimed to desensitize head and body motion sensitivity and reduce the pathologic response to motion.[1,10,11] The intervention also provided the patients with coping strategies in daily life situations, such as walking in shopping centers, keeping their balance in the dark, and taking the bus, by the use of substitution exercises. In addition, by increasing awareness to challenges, the patients were gradually able to expose themselves to and take control of situations that provoked dizziness by the

Table 6.
Elements of Systematic Modifications of the Intervention in Patients With Mild Traumatic Brain Injury

Challenge	Modification of Exercises, Activities, and Environment
Fatigue/poor stamina	Avoid activity levels that provoke or exacerbate symptoms. Coordination of physical, social, and work-related activities; when increasing one activity, reduce or keep other activities at the same level. Begin exercises more gently and increase more slowly than for acute vestibular deficits Daily exercise plan/home exercise program (HEP) to overcome avoidance of provocative stimuli Encourage rest between activities Breaks during exercises to improve adherence and limit exacerbation of symptoms
Limited cognitive resources Short-term memory and concentration problems	Clear and concise information in both written and verbal forms Written HEP instructions with figures/pictures Text message reminder of group sessions
Slowed processing and impaired ability to shift attention or multitask	Avoid dual-task exercises initially. Gradual exposure to dual-task and multitask exercises.
Headache	Do exercises that do not increase symptoms/pain Medical management for resolution of headache to increase exercise and activity tolerance
Musculoskeletal injuries, especially neck pain and reduced active range of motion	Eye-head coordination and habituation exercises within pain-free range of motion. Focus on good posture for head and neck when performing exercises. Physical therapy or medical management, depending on the patient's capacity and severity of the neck pain
Visual disturbances Decreased tolerance of complex visual environment/visual motion intolerance	Avoid/decrease watching screens (eg, TV, smartphones, computers). Instructions to "rest" eyes by looking at targets at a distance. Advice on the use of filter screens and glasses. Gradually include exercises that include visual flow and complex visual stimuli Avoid complex environments initially (eg, shopping malls, heavy traffic), gradual exposure based on symptoms Encourage use of indoor and outdoor settings that patients typically encounter to promote reintegration into daily activities
Sensitivity to light, sound	Avoid exposure: dim lights, curtains, sunglasses/filter glasses, wearing caps. Earplugs, headphones. Gradually increase exposure as tolerated.
Emotional distress, depression, and anxiety	Verbal and written information about usual symptoms after traumatic brain injury. Peer support. Reassurance that symptoms are likely to improve over time, but might vary. Relaxation techniques. Medical or psychological management may be indicated.

use of vision, proprioception, and attention.

Vestibular rehabilitation appears more effective in patients who have their headaches under control.[10] All patients in the current case series used painkillers when needed and were able to control their headaches. Because several of the exercises involved movement of the head and neck, the patients had to tolerate such movements.[7,11] Patients 1 and 4 had neck pain and reduced AROM. They were instructed to perform the VR exercises in a modified manner, within a pain-free AROM. Patients with severe neck pain may not do well with VR exercises until their neck problems are treated. Patient 1 saw a chiropractor for neck pain during the intervention, which might have increased the benefit of the VR intervention.

In patient 2, we found a positive DVAT, indicating impaired VOR. After TBI, impaired VOR may be due to both peripheral and central vestibular injury or dysfunction.[7] Restoration of dynamic gaze stability was facilitated by the gaze stabilization exercises,[1] and the DVAT was normalized during the intervention period.

The patient with BPPV (patient 3) is a reminder of its relatively common prevalence after TBI.[28] Patients with TBI account for 5% to 28% of all cases of BPPV[1,28] and, therefore, should be assessed for BPPV when complaining of vertigo or dizziness. Multiple canal involvement, such as combinations of PSC-BPPV and HSC-BPPV as in patient 3, does not appear to be more common after trauma.[28] However, there are some indicators that traumatic BPPV can be more difficult to treat than idiopathic BPPV.[28] Despite negative tests for BPPV after reposition maneuvers, our patient reported ongoing symptoms of dizziness, indicating other causes of dizziness in addition to BPPV, which is not uncommon after TBI.[27]

The poorer outcome for patient 4 might be explained by a higher symptom pressure at baseline and comorbidities. It also may be explained by the positive computed tomography scan, which indicated a more severe injury, and a possible combination of central posttraumatic vertigo and peripheral vestibular dysfunction. The central nervous system compensation associated with VR might take longer for patients with TBI due to central affection.[11] Furthermore, postconcussion symptoms and concurrent physical, cognitive, and emotional disorders might disturb the natural recovery and central nervous system compensation of dizziness and balance problems after TBI.[7] Based on this reasoning, patient 4 might have benefited from a prolonged VR intervention period. Gottshall[10] described that many patients with TBI respond to VR over a period of 8 weeks. However, some patients, like patient 4, need a slower progression and might continue to improve over an additional 4 to 8 weeks.[10] In our case series, however, the goal is to describe and examine the outcomes for an 8-week program.

The balance training addressed difficulties with reduced sensory integration and the visual dependency pattern seen in all 4 patients at baseline. This was done by focusing on balance exercises with eyes closed, promoting reliance on somatosensory and vestibular cues for balance, which might be attributed to the improved scores on the BESS test. Furthermore, the patients did not appear to have substantial difficulties with mobility measured with the HiMAT at baseline. This finding might be explained by the fact that the HiMAT does not specifically challenge the visual and vestibular systems, which might have been better assessed with the Dynamic Gait Index.[1] Moreover, mobility tests such as the HiMAT and Dynamic Gait Index tend to have ceiling effects in the mild TBI population, which also can explain the minimal change on the HiMAT that was observed in this case series.[25,29]

It is documented that aerobic exercise training after TBI may reduce deconditioning, fatigue, and psychological distress.[30] Thus, the increased activity level reported by all 4 patients might have contributed to the observed changes in several of the self-reported outcome measures. Additionally, psychological distress might be positively influenced by increased self-efficacy, confidence, and knowledge.[8]

To summarize, the modified group-based VR intervention appeared safe, viable, and beneficial when addressing dizziness and balance problems after TBI. We think the present case series might be useful for practitioners in tailoring VR interventions for patients with TBI and dizziness and balance problems. Future RCTs are warranted to evaluate short- and long-term effects of VR interventions in patients with TBI.

All authors provided concept/idea/project design and writing. Ms Kleffelgaard and Mrs Bruusgaard provided data collection. Ms Kleffelgaard and Dr Soberg provided data analysis and project management. Ms Kleffelgaard provided participants. Dr Soberg, Mrs Bruusgaard, Dr Tamber, and Dr Langhammer provided consultation (including review of manuscript before submission).

The study was approved by the Regional Committee for Medical Research Ethics in Norway (#2012/195b 20120306).

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eAppendix 1.
Fitness Diary

Name: Date/week:

	Morning	Midday	Evening
Day 1	Exercise 1 2 3 4 5	Exercise 1 2 3 4 5	Exercise 1 2 3 4 5
Day 2	Exercise 1 2 3 4 5	Exercise 1 2 3 4 5	Exercise 1 2 3 4 5
Day 3	Exercise 1 2 3 4 5	Exercise 1 2 3 4 5	Exercise 1 2 3 4 5
Day 4	Exercise 1 2 3 4 5	Exercise 1 2 3 4 5	Exercise 1 2 3 4 5
Day 5	Exercise 1 2 3 4 5	Exercise 1 2 3 4 5	Exercise 1 2 3 4 5
Day 6	Exercise 1 2 3 4 5	Exercise 1 2 3 4 5	Exercise 1 2 3 4 5
Day 7	Exercise 1 2 3 4 5	Exercise 1 2 3 4 5	Exercise 1 2 3 4 5

Circle performed exercises

Goals for the week:

Did I achieve my goals?

If not, what was the reason?

What motivates me?

What is holding me back?

Long-term goals:

Describe physical and psychological reactions to the exercises:

Underline or describe in own words:

Physical: feeling good, uncomfortable, painful, dizzy, sick/nausea

Other reactions:

Psychological: fear, anxiety, doubt, glad, motivated, unsafe, impatient, angry

Other reactions:

Aerobic exercise program

Exercise	Duration (min)	Intensity–Borg Scale Rating of Perceived Exertion[a]

Find your exercise tolerance level:

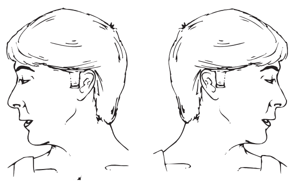
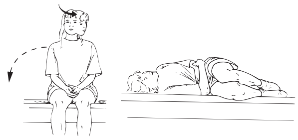
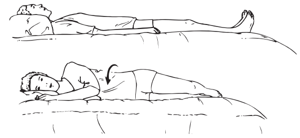
If you experience increased symptoms such as headache or pressure in the head, dizziness, and foggy thinking on your exercise intensity level on the Borg scale, decrease it by 1 or 2 levels. Exercise on this level for 2 to 3 weeks before you increase by 1 or 2 levels. Alternatively, you can reduce the duration of your exercise.

[a] Borg G. Perceived exertion as an indicator of somatic stress. *Scand J Rehabil Med.* 1970;2:92–98.

eAppendix 2.

Examples of and Rationale for the Exercises in the Modified Vestibular Rehabilitation Intervention[a]

Habituation exercises: Habituation exercises are used to treat motion-provoked vertigo/dizziness and to reduce symptoms of dizziness by repetitive exposure to the movements that provoke the symptoms to habituate the system and thereby reduce the pathologic response to the stimuli.[1-3]

Head turns horizontally and vertically	Brandt-Daroff exercises	Rolling supine to left side and supine to right side
		
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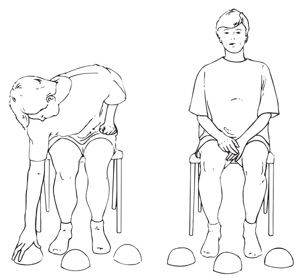
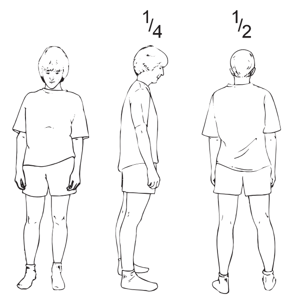
Diagonals head to knee	Diagonals head to floor	Turning 90° and 180°
		
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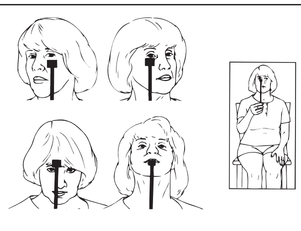
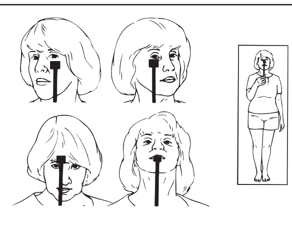
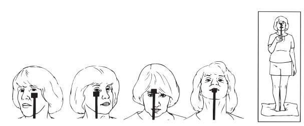
Adaptation exercises: Adaptation exercises are used to restore dynamic gaze stability (the ability to maintain focus while the head is moving). Restoration of dynamic gaze stability is facilitated by exercises that promote adaptation of an uncompensated vestibulo-ocular reflex.[1,2,4,5]

X1 viewing exercise: The patient focuses on a stationary target while turning his or her head back and forth.

X2 viewing exercise: The target moves in the opposite direction of the head movement.

A paper with a large letter "A" and a small letter "A" is used as a far (1.5–2 m) and near (held in hand, at arm's length) target, respectively, for the exercises.

X1 viewing exercise sitting	X1 viewing exercise standing	X1 viewing exercise standing on foam
		
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eAppendix 2
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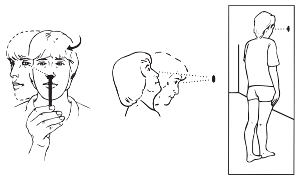
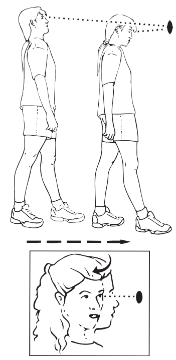
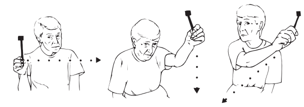
X1 viewing exercise tandem	X1 viewing exercise walking	X2 viewing exercise
		
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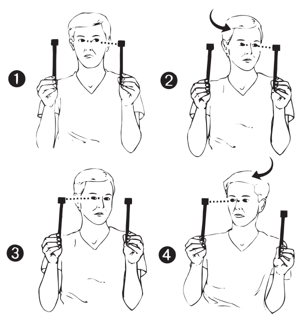
Substitution exercises for gaze stability: Substitution exercises for gaze stability promote the use of other eye movements to compensate for impaired vestibular function. One strategy is to facilitate preprogrammed eye movements using large eye movement on a target before the head turns to the target. Another strategy is to enhance the use of cervical inputs to generate the eye movement that will keep the eye on target or enhance cortical coactivation, which produces the head movement and the eye movement.[1]

Active eye-head movement between 2 objects: The objects (paper with letters “X” and “Y”) are placed on a wall 1.5–2 m in front of the patient. The patient practices eye movements toward the object on one side (“X”) and then rotates the head in the same direction until the object is straight ahead while maintaining visual fixation on the object all of the time. Then, these eye movements are repeated in the opposite direction (the patient moves the eyes to focus on the “Y”, and while keeping “Y” in focus, moves the head toward the “Y”).

Active eye-head movement between 2 objects

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Remembered/imagined target: The patient focuses on a target straight ahead, and then with eyes closed, the patient moves the head while trying to keep the eyes stabilized on the target. After moving the head, the patient opens the eyes to see if he or she has kept the eyes on the target.

Balance exercises: Balance exercises help to improve the organization of sensory information for balance control and to promote utilization of vestibular cues for balance. In addition, balance reactions on both expected and unexpected perturbations, as well as dual tasks, are performed.[3–7]

(Continued)

eAppendix 2
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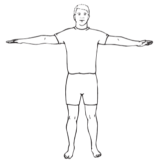
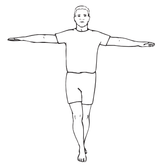
Standing static balance exercises:

Standing static–feet apart, varied arm positions	Standing static–tandem Varied arm positions	Feet together, eyes closed Tandem, eyes closed
		
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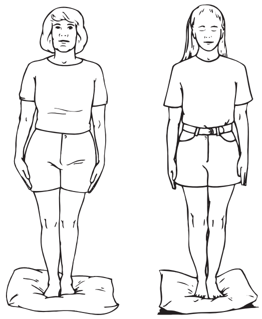
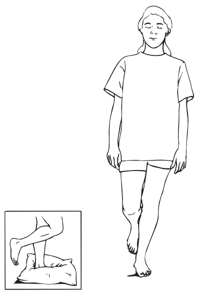
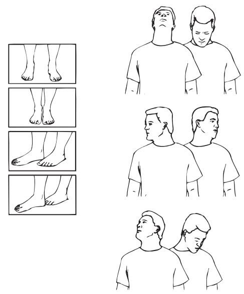
On compliant surfaces, eyes open and closed	Compliant surface, one leg	Different foot positions with head motion
		
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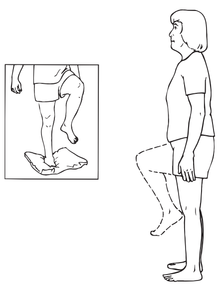
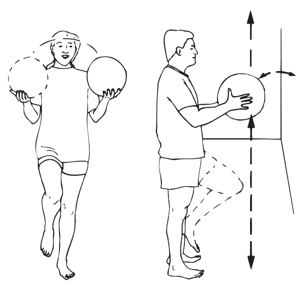
Standing dynamic balance exercises:

Weight shifts anterior/posterior	Marching in place on floor or compliant surface	Throwing/catching/bouncing a ball
		
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eAppendix 2
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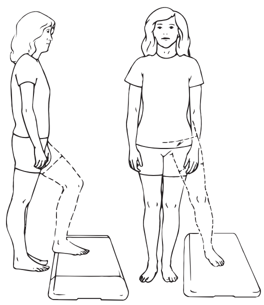
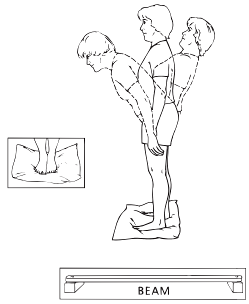
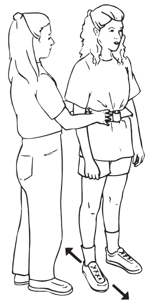
Stepping up/down forward and sideways	Reactive balance on beam or foam surface	Reactive balance
		
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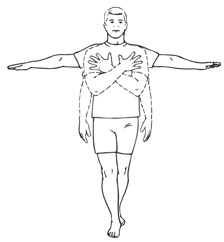
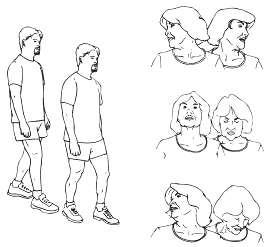
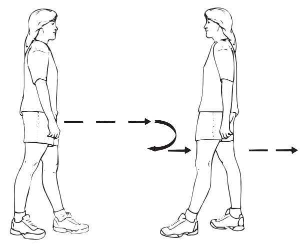
Balance exercises during walking/gait:

Heel-toe tandem walk, eyes open and eyes closed	Side to side, up/down, diagonal head motion while walking	Walking forward/backward
		
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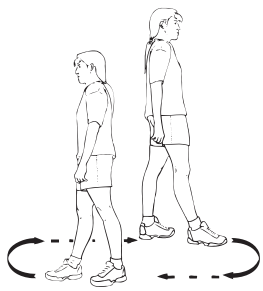
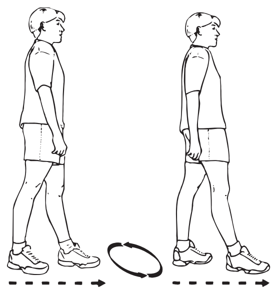
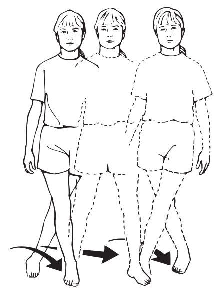
Walking with half turn 180°	Walking with full turn 360°	Cross-overs
		
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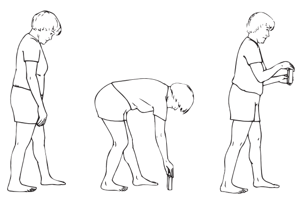
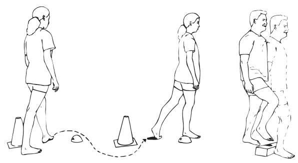
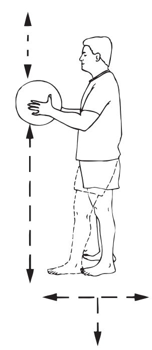
Picking up/carrying objects	Obstacle course	Walking while bouncing/catching a ball
		
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[a] Illustrations are from the library of Visual Health Information Stretching Charts Inc (VHI), Tacoma, Washington; phone number: 1-800-356-0709.