

Implementing reactive balance training in rehabilitation practice

A guide for healthcare professionals



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ABBREVIATIONS

RBT = reactive balance training

GLOSSARY

Postural control	The ability to control ‘static’ posture (e.g., sitting or standing still).
Anticipatory balance control	The ability to control balance (i.e., prevent falling) during voluntary movement.
Balance perturbation	A perturbation is a deviation or disturbance from the normal state. A balance perturbation occurs when there is a disruption to the relationship between the centre of mass and the base of support resulting in a loss of balance. After experiencing a loss of balance, the person will fall if they do not take some corrective action (e.g., a reactive step).
Reactive balance control	The ability to respond to a loss of balance (or balance perturbation), to prevent a fall.
External perturbation	A loss of balance caused by an external force (e.g. push or pull from the physiotherapist; see toolkit videos for examples).
Internal perturbation	A loss of balance caused by failure of postural or anticipatory balance control during voluntary movement, where there is no external force (see toolkit videos for examples).
Fall	“An event that results in a person coming to rest unintentionally on the ground or other lower level”. ¹
Reactive balance training	A type of balance training method where clients experience intentional balance perturbations that require them to execute balance reactions to prevent a fall.
Volitional step training	A type of exercise where the client practices stepping in various directions, but does not necessarily experience a balance perturbation.

1.0

INTRODUCTION

In this chapter

- What is reactive balance control?
- What is reactive balance training?
- What is the evidence for reactive balance training?
- What are the risks with reactive balance training?

1.1 About this guide

This guide describes the reactive balance training (RBT) approach developed at the KITE Research Institute at University Health Network. This approach primarily focuses on improving control of reactive stepping, using internal and manual external perturbations to balance. Versions of this program have been used for rehabilitation of people with stroke, acquired brain injury, and spinal cord injury. Section 1.4 summarizes the current state of the evidence for RBT across different populations. Further details about this RBT approach, including resources to help plan training programs and videos demonstrating training approaches, are available at <https://kite-uhn.com/tools/rebal>.

RBT must be delivered by appropriately trained and licensed physiotherapists; other qualified healthcare providers might also be able to deliver RBT (e.g., registered kinesiologists, occupational therapists). A comprehensive sensorimotor and balance assessment is required prior to implementing RBT. RBT is deliberately challenging to balance control and there is a chance that participants will be unable to regain stability and fall; appropriate safety precautions should be in place to reduce the risk of injury to the participant (see details within the document). ***The information provided within this document does not replace clinical judgement.***

1.2 What is reactive balance control?

A loss of balance, or balance perturbation, happens when someone loses control of the relationship between the centre of mass and base of support. Reactive balance control is the ability to respond to this loss of balance and prevent a fall.² Balance reactions can be classified as ‘change-in-support’ or ‘fixed support’ reactions.³ For change-in-support reactions, the size of the base of support changes to re-capture the falling centre of mass (e.g., stepping or reach-to-grasp reactions). For fixed support reactions, the base of support does not change (e.g., hip or ankle strategy). Change-in-support reactions are very important as they are the only option for responding to a large balance perturbation, and are preferred when people are able to respond freely.⁴ Reactive balance control is distinct from anticipatory balance control. Anticipatory balance control is the ability to control balance before and during voluntary movement; for example, shifting weight to the stance limb before starting to walk.

When people who have poor anticipatory balance control are mobile and physically active, they are at increased risk of losing balance. If they also have poor reactive balance control, they are at risk of falling after this loss of balance. It is important to remember that there are complex relationships between underlying sensorimotor and cognitive impairments (e.g., due to aging or neurological disease), walking ability, physical activity, falls, injuries, fear of falling, and both reactive and anticipatory balance control (Figure 1.1).⁵

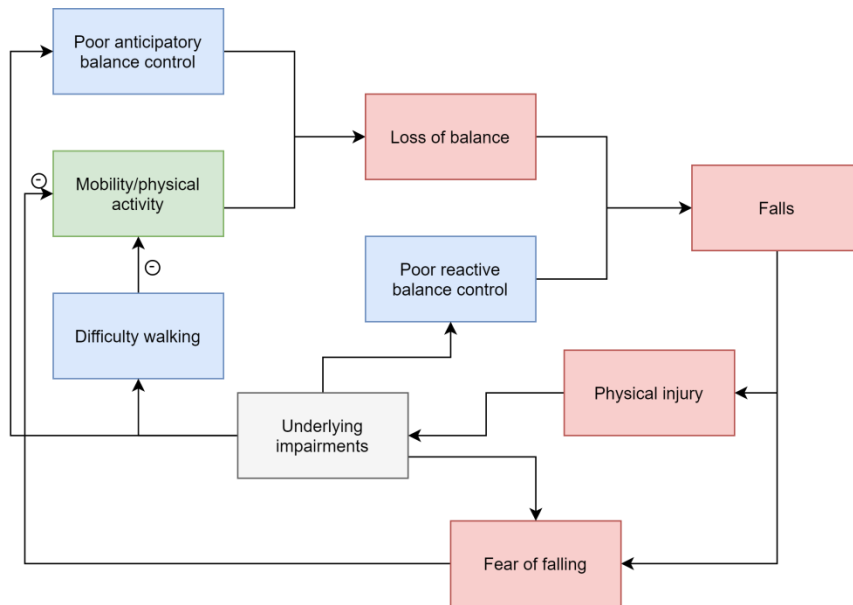


Figure 1.1. The complex relationship between anticipatory and reactive balance control and falls. Figure modified from Mansfield et al., 2018. The minus sign indicates a negative relationship between two items; e.g., people who have difficulty walking will reduce their levels of mobility and physical activity.

1.3 What is reactive balance training?

The **goal of reactive balance training (RBT)** is to improve reactive balance control to promote safe independent mobility. RBT is a balance training method where clients experience **intentional** losses of balance (or balance perturbations) that require them to use balance reactions to prevent a fall. By repeatedly practicing these balance reactions, clients should improve their reactive balance control. In RBT, the balance perturbations can be:

- ‘internal’ (e.g., client loses balance while completing challenging balance tasks); or
- ‘external’ (caused by an external force, such as a push or pull from the therapist, or from a device such as a programmable treadmill).

The perturbations during RBT are typically unannounced to mimic the accidental and unexpected nature of falls in daily life.⁶ However, perturbations that are predictable in timing and/or direction can be used early in training to help acclimate clients to RBT or to initially target training of a specific feature of balance reactions.

The term ‘perturbation-based balance training’ (or just ‘perturbation training’) is also used to describe RBT. We prefer the term ‘reactive balance training’ for a few reasons. The goal of RBT is for clients to improve their reactive balance control. Therefore, clients should not just experience balance perturbations, but should also use and practice balance reactions. RBT should be done in such a way that clients **react to, rather than resist**, the perturbation. For example, if the perturbations are always predictable (in direction, timing, and force), clients will learn the specific perturbation features and learn to resist the

perturbations rather than react to them. The term ‘perturbation training’ is also used to refer to a training strategy to improve stability of a single joint after soft-tissue injury or surgery.⁷ The term ‘reactive balance training’ distinguishes RBT from this type of perturbation training.

1.4 What is not reactive balance training?

The following balance training approaches are not necessarily RBT:

- Balance training on unstable surfaces, where the goal is to *maintain* balance.
- Balance training with sensory perturbations (e.g., closing the eyes).
- Step or reach-to-grasp training where the movements are voluntary and the client does not lose balance.
- Balance training with perturbations that are ***always*** predictable in direction, timing, and force, so that clients can learn feedforward or anticipatory strategies to maintain balance during the perturbations.

With this in mind, predictable perturbations and/or volitional step training can be useful to include as part of an RBT program, particularly in early stages, to help clients get comfortable with the perturbations and practice the movements involved in the reaction. Likewise, unstable surfaces or sensory perturbations can be used as part of an RBT program (see details in other sections of this toolkit).

1.5 Evidence for reactive balance training

The evidence for the effect of reactive balance training on frequently-reported outcomes is summarized in Table 1.1.

Randomized controlled trials typically find that RBT improves reactive balance control more than other types of exercise, such as stretching,⁸ unperturbed walking,^{9–11} strength training,^{12–14} or ‘traditional’ balance training with a focus on improving anticipatory balance control.^{15–19} The finding that RBT improves reactive balance control is consistent with the specificity of training principle; that is, RBT specifically aims to improve reactive balance control, but other balance training programs do not.²⁰ Some studies have found that these improvements in reactive balance control last for several months to a year after the end of the training program;^{17,21,22} these findings contrast with other exercise interventions where training effects are quickly lost after training has ended.

Most clinical trials of RBT are small and do not have sufficient power to show superiority of RBT compared to other training approaches on rate of falls in daily life.²³ However, a systematic review and meta-analysis of 29 small randomized controlled trials found that the rate of falls was about 40% lower for people who completed RBT compared to people who completed a control intervention.²⁴ Studies included in this review included apparently healthy older adults, older adults with mixed diagnoses, and people with Parkinson’s disease, sub-acute and chronic stroke, cerebral palsy, and incomplete spinal cord injury.²⁴

One study among apparently healthy older adults observed a greater improvement in balance confidence for the RBT group (perturbed treadmill walking) compared to the control group (unperturbed treadmill walking).²⁵ Other randomized controlled trials have found that

RBT has similar effects as other balance training approaches or exercise interventions for improving balance confidence or fear of falling (Table 1.1). That is, when improvements in balance confidence or fear of falls were observed for the RBT group they were also observed for the control group. Likewise, when studies do not observe an improvement in balance confidence or fear of falling for the RBT group an improvement is also not observed for the control group.

Table 1.1: Summary of evidence for reactive balance training

Outcome	Evidence statements	Population studied
Reactive balance control	RBT is superior to other balance training approaches for improving reactive balance control	Apparently healthy older adults ^{8-12,15,26,27} Multiple sclerosis ^{16,28} Parkinson's disease ^{13,14} Sub-acute & chronic stroke ^{17-19,29}
Falls in daily life	RBT is likely superior to other balance training approaches or exercise interventions for preventing falls in daily life ²⁴	Parkinson's disease ^{13,30}
Other balance and mobility measures	RBT is similar to other balance training approaches for improving other balance and mobility measures (e.g., Berg Balance Scale scores, Timed Up and Go times, or postural sway)	Apparently healthy older adults ^{8,10,25,31-34} Incomplete spinal cord injury ³⁵ Parkinson's disease ^{21,36-38} Chronic stroke ^{17,39,40}
Balance confidence/fear of falling	RBT has similar effects on balance confidence/fear of falling as other balance training approaches or exercise interventions	Apparently healthy older adults ²⁵ Incomplete spinal cord injury ³⁵ Chronic stroke ^{17,40,41}
Reaction time	RBT is superior to other balance training methods for improving volitional reaction time	Apparently healthy older adults ^{27,33,42} Older adults with mixed diagnoses ⁴³ Chronic stroke ¹⁸ Parkinson's disease ⁴⁴

There is no evidence that RBT can improve physiological fall risk factors (e.g., sensory impairment),^{26,45} or measures of disease severity (e.g., Hoehn and Yahr stage for Parkinson's disease³⁰ or Fugl-Meyer scores for stroke⁴⁶). It is unclear from randomized controlled trials if RBT can improve lower extremity muscle strength or power as findings are mixed.^{8,12,28,34,39,41,47,48} There is no evidence that people increase their daily physical

activity,^{17,25,45} have improved quality of life,^{17,34,49} or increase participation in daily activities³⁹ after completing RBT. One small study among people with chronic stroke reported improved cardiorespiratory fitness and walking endurance following 12 weeks of manual RBT,⁴¹ whereas another study among adults with vision loss did not report improved cardiorespiratory fitness following 12 weeks of RBT on a shifting wooden platform, combined with anticipatory balance training.⁵⁰

Randomized controlled trials of RBT to date have included apparently healthy older adults, older adults with mixed diagnoses, people with neurological conditions (multiple sclerosis, incomplete spinal cord injury or disease, Parkinson's disease, and stroke), adults with obesity, and adults with vision loss (Table 1.1). Therefore, evidence for the effectiveness of RBT is limited to these populations. Case studies, case series, non-randomized controlled studies, and crossover studies provide evidence for the feasibility and potential efficacy of RBT among people with conditions such as progressive supranuclear palsy,⁵¹ cerebral palsy (children and adults),^{52–54} and unilateral amputation.⁵⁵

1.6 Risks with reactive balance training

Evidence currently suggests that the most frequent adverse events related to RBT are similar to those observed with other types of exercise (e.g., muscle or joint pain, fatigue).²⁴ However, a few adverse events seem to occur more frequently with RBT than with other types of exercise. Table 1.2 summarizes the adverse events that have been reported across 21 randomized controlled trials of RBT that included apparently healthy older adults, sedentary older adults, older adults referred to a falls clinic with various diagnoses, people with chronic or sub-acute stroke, people with Parkinson's disease, people with incomplete spinal cord injury or disease, adults with cerebral palsy.²⁴

Two studies reported pain or injuries, most of which were mild, that were related to being caught by the safety harness during RBT.^{15,26} For two participants in one study, these injuries required withdrawal from the study; however, the investigators changed the style of safety harness during the study, and believe that this change prevented further injuries.²⁶ One study reported a fall, without injury, when participating in RBT without a safety harness.³⁵

Subjective or psychological adverse events are reported with RBT, but typically not with other types of exercise. Clients may express anxiety related to the balance perturbations and/or fear of falling or injury. Clients who experience anxiety with RBT are at risk of withdrawing from the intervention,²⁴ and therefore no longer receiving the benefits. Therapists should be mindful of clients' emotional state during RBT, and consider modifying the training program to avoid increasing anxiety (see Section 3.4). Falls in daily life due to increased balance confidence and/or risk taking can also be a consequence of RBT. Indeed, one study reported a significantly reduced fear of falling and increased risk of falls after training for older adults who completed RBT compared to no intervention.⁵⁶ Therefore, therapists might consider including education on fall risks in addition to RBT to help to prevent falls in daily life. Alternatively, increased fall rates might not be considered a negative outcome if the client feels empowered to complete daily activities independently and the falls do not lead to injury or restricting activity.^{57,58}

Table 1.2. Adverse events reported in studies of reactive balance training.²⁴ The list reflects adverse events that were reported for RBT. Bolded text indicates adverse events that, despite being rare or infrequent, were reported in the RBT groups but not in the control groups, who completed another type of exercise or balance training.

	Rare adverse events (reported by <1% of participants)	Infrequent adverse events (reported by 1-19% of participants)	Likely or very likely adverse events (reported by >20% of participants)
Minor <i>Alleviated with rest and/or medication May require adaptation of training program</i>	<ul style="list-style-type: none"> • Seizure • Headache • Upper extremity pain • Back pain • Falls in daily life due to increased risk taking • Fall during training (without injury)* 	<ul style="list-style-type: none"> • Fatigue • Muscle soreness • Musculoskeletal injury • Dizziness • Pain (non-specified) • Lower extremity pain • Anxiety 	<i>None reported to date</i>
Moderate <i>Requires hospitalization and/or results in withdrawal from the intervention</i>	<ul style="list-style-type: none"> • Musculoskeletal injury[†] • Anxiety • Fear of injury • Back pain 	<ul style="list-style-type: none"> • Lower extremity pain 	<i>None reported to date</i>
Severe <i>Leads to lasting or permanent change in function, disability, or death, or is life threatening</i>	<ul style="list-style-type: none"> • Musculoskeletal injury[‡] 	<i>None reported to date</i>	<i>None reported to date</i>

*The client not wearing a safety harness at this time.

[†]Injuries related to being caught by the safety harness.²⁶

[‡]One participant assigned to the RBT group experienced a hip fracture after a fall that occurred during a non-RBT component of the intervention.

2.0

SCREENING AND ASSESSMENT

In this chapter

- Contraindications, precautions, and screening for reactive balance training
- Assessing reactive balance control
- Other assessment considerations

2.1 Screening

Clinical judgement will prevail, but please consider the following and when in doubt consult the expertise of other healthcare professionals (e.g. physician) or err on the side of caution for yourself and the client.

You should use your clinical judgement with respect to client- and therapy-related goals. Clients and therapists may choose not to participate in RBT if it is not relevant to the plan of care or client rehabilitation goals, despite being eligible for RBT. When considering eligibility, also consider acuity and severity of injury or health conditions.

General contraindication:

Table 2.1 provides guidelines regarding contraindications and precautions for RBT. Note that ***this is not an exhaustive list of conditions***. In general, any clients with an illness, injury, or condition that may be exacerbated by repeated exposure to balance perturbations and/or that would prevent wearing a safety harness should not participate in RBT. RBT should be discontinued, paused, or reduced in intensity if a client reports joint pain or worsening of an existing condition (see Section 1.6).

Table 2.1: Recommended contraindications and precautions for reactive balance training.

Contraindications	Precautions - consult with healthcare team before proceeding with RBT
<u>Musculoskeletal:</u> <ul style="list-style-type: none"> • Weight bearing restrictions in lower extremity • Acute trauma, hip or knee arthroplasty or other surgery, fractures, soft tissue injury • Severe instability in hips, knees, ankles (could be musculoskeletal or neurological in origin) • Acute low back or lower limb pain • Halo orthosis or cervical collar • History of lower extremity fragility fracture/severe osteopenia/osteoporosis 	<ul style="list-style-type: none"> • Weight bearing restrictions in the upper extremity* • Arthritis (including osteoarthritis, rheumatoid arthritis, ankylosing spondylitis and other forms of arthritis) – consider active/acute flares, and monitor for pain during/after the session • Instability in hips, knees, ankles (could be musculoskeletal or neurological in origin)*

Contraindications	Precautions - consult with healthcare team before proceeding with RBT
<u>Musculoskeletal (continued):</u> <ul style="list-style-type: none"> Limited range of motion of lower extremity joints that may pose risk of injury (e.g., due to contractures) 	
<u>Cardiorespiratory/cardiovascular:</u> <ul style="list-style-type: none"> Cardiac event or surgery where activity restrictions are still in effect Abnormal or unstable cardiovascular responses to exercise (e.g., see contraindications to exercise from the American College of Sports Medicine⁵⁹) Arterial dissection** 	<ul style="list-style-type: none"> Tracheostomy Postural hypotension/low blood pressure Hypertension
<u>Neurological:</u> <ul style="list-style-type: none"> Craniotomy without a helmet Severe spasticity in the legs 	<ul style="list-style-type: none"> Shoulder subluxation with sling* Craniotomy with helmet History of seizures Epilepsy Chronic subdural hemorrhage Dizziness/vertigo Poor sensation/proprioception* Autonomic dysfunction (spinal cord injury)***
<u>Cognitive/communicative:</u> <ul style="list-style-type: none"> Unable to understand the purpose of the training and/or to provide informed consent Unable to reliably communicate pain or discomfort 	<ul style="list-style-type: none"> Cognitive impairments (decreased attention, impulsivity, low frustration tolerance, decreased judgement) Communication impairments Hearing impairments
<u>Functional mobility:</u> <ul style="list-style-type: none"> Unable to stand unsupported with or without a gait aid 	
<u>Other:</u> <ul style="list-style-type: none"> Acute illness – vomiting, migraine, fever etc. Body mass exceeds the limits of safety harness system (see Section 3.5.2) Colostomy bags 	<ul style="list-style-type: none"> Pregnancy High anxiety/fear of falling and/or history of traumatic falls Medications affecting balance Hypo/hyperglycemia

Contraindications	Precautions - consult with healthcare team before proceeding with RBT
<p><u>Other (continued):</u></p> <ul style="list-style-type: none"> • Indwelling catheters • Pressure sore on pelvis or trunk 	<ul style="list-style-type: none"> • Hernias • Nasopharyngeal/gastrostomy tubes • Infection control issues (e.g., C-diff, MRSA) – consult your institution’s infection control policies regarding proceeding with therapy in these cases and/or appropriate precautions (gown, gloves, wipe down equipment etc)
<p>Additional notes:</p> <p>*Use a sling or ankle stabilizer/brace as needed for clients who present with joint instability, sensory impairment etc., for safety (see Section 3.5.3).</p> <p>**Arterial dissections can be a contraindication or precaution and should be considered on a case-by-case basis. Consider acuity of event. Consult with physician. Consider monitoring blood pressure during training.</p> <p>***Monitor for signs and symptoms of autonomic dysreflexia (increase in systolic blood pressure of 20-30 mmHg) in individuals with spinal cord injury above T6. This is typically triggered by noxious stimulus below the level of the spinal injury, such as the harness straps being applied too tightly, and is considered a medical emergency.</p>	

2.2 An initial comprehensive assessment is required to inform treatment and ensure client safety

Reactive balance assessment and training should occur within the context of a more comprehensive assessment of the individual. Complete an initial assessment to ensure that RBT will be safe for the client (see Section 2.1), to understand how RBT aligns with the client’s goals, and to identify other underlying impairments that may affect reactive stepping and need to be considered in the treatment plan. Obtain information regarding significant medical history, relating to contraindications and precautions. Modifications to the manner in which the program is provided may be made based on past medical history. For example, some activities might be avoided to prevent exacerbation of a previous injury.

2.3 Reactive balance assessment

Observation of client responses to the ‘reactive’ component of the Balance Evaluation Systems Test, or a modified version of the Push-and-Release test, can be used to identify impairments in reactive balance control. See Table 2.2 for impairments commonly observed and features that are linked to increased falls risk in daily life. Use the Assessment Data Collection Sheet (Appendix 1) to document assessment conditions and client responses. Use the Treatment Planning Guide (Appendix 2) to document the specific areas of dyscontrol that you observe.



The initial assessment includes:

- Identification of clients' rehabilitation goals
- Assessment of underlying impairments (especially those related to impaired reactive stepping):
 - Motor function, strength, range of motion
 - Sensory impairment (e.g. ankle proprioception and plantar sensation)
 - Visual/perceptual impairments
 - Cognitive impairment
 - Fear of falling or balance confidence – e.g., using the Activities-specific Balance Confidence scale⁶⁰
- Functional mobility status
- Assessment of reactive stepping (Section 2.3); recommend using:
 - Forward-fall lean-and-release perturbations;²³ and/or
 - Observation of reactions in the 'reactive' component of the Balance Evaluation Systems Test or the Push-and-Release test^{61–63}

2.3.1 Equipment/instrumentation

- **Safety equipment:** *Clients should wear a safety harness attached to a secure point overhead* to prevent a fall to the floor. Some clients may also require ankle support (e.g., an ankle-foot orthosis or brace), even if they do not typically use one during walking or other activities. The same safety considerations apply for reactive balance assessment as for RBT (see Section 3.5).
- **Video camera** (optional): Balance reactions are fast, and it can be difficult to administer the test, be mindful of client safety, and observe the responses all at once. Video recording the test allows you to replay the client's responses several times to observe features of the response that you might have missed 'in the moment' during the assessment.
- **Force plates, weighing scales** (optional): If you have access to these instruments, you can place two force plates or weighing scales side-by-side. If the client places one foot on each, you can observe weight-bearing asymmetry in standing or prior to the perturbation. Force plates may also provide information about delays in timing of step initiation and execution. If these instruments create a raised surface, ensure that there is enough space on this raised surface for the client to execute the step reaction.
- **Obstacles** (optional): Obstacles can be used to block stepping with one limb and force use of the non-preferred limb (see modifications below). Alternatively, you can use your own foot to block the step, but might find this difficult to coordinate if you are administering the test alone.

The instructions below are modified from

http://bestest.us/files/9613/4756/3990/BESTest_Script.pdf

Table 2.2: Frequently-observed areas of reactive balance dyscontrol. See Appendix 2 for suggestions for documenting these areas of dyscontrol, and RBT strategies to target them.

Area of dyscontrol	Link to falls in daily life
Failed step reactions – requires external assistance (from the therapist and/or safety harness) to regain stability	People with sub-acute stroke ⁶⁴ People with Parkinson's disease ⁶⁵
Multi-step reactions	Apparently healthy older adults ^{66–70} People with Parkinson's disease
Executes step reactions at lower perturbation magnitudes	Apparently healthy older adults ^{71,72}
Does not step when the magnitude of perturbation requires a step	People with sub-acute stroke ⁶⁴
Low foot clearance during reactive steps (foot slides or shuffles)	People with sub-acute stroke ⁶⁴
Delayed reactions	People with multiple sclerosis ⁷³
Unwilling/unable to step with both limbs	People with chronic stroke ⁷⁴
Stands asymmetrically prior to the perturbation	No evidence, but may increase difficulty of stepping with either limb or contribute to delayed stepping reactions ⁷⁵
Short reactive steps	Apparently healthy older adults ⁶⁷
Attempts to use the upper extremity to regain stability	No evidence, but may accompany failed step reactions or suggest fear of falling
Falls laterally on step termination when responding to antero-posterior perturbations	Apparently healthy older adults ⁶⁶
Experiences limb collisions when responding to lateral perturbations	Apparently healthy older adults ⁶⁶

2.3.2 Tests

Forward direction

Stand in front of the client with one hand on each shoulder and ask them to lean forward (make sure there is room for them to step forward). Ask them to lean until their shoulders and hips are in front of their toes. Suddenly release your support when the client is in place (Figure 2.1).

Instructions to the client:

“Stand with your feet shoulder width apart, arms at your sides. Lean forward against my hands beyond your forward limits. When I let go, do whatever is necessary to avoid a fall. If you need to take a step, try to take as few steps as possible.”

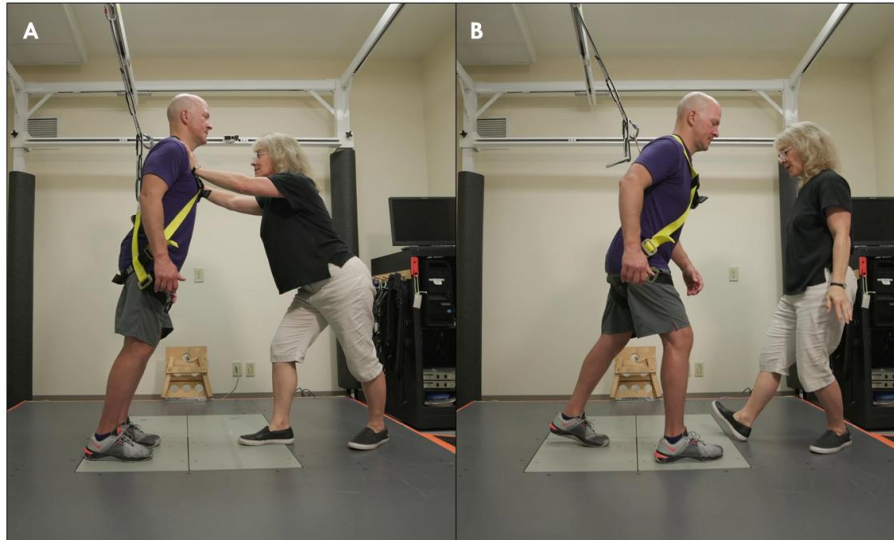


Figure 2.1. Forward-directed lean-and-release test.

Backward direction

Stand behind the client with one hand on each scapula and ask them to lean backward (make sure there is room for them to step backward). Ask them to lean until their shoulders and hips are over their heels. Release your support when the client is in place (Figure 2.2).

Instructions to the client:

“Stand with your feet shoulder width apart, arms at your sides. Lean backward against my hands beyond your backward limits. When I let go, do whatever is necessary to avoid a fall. If you need to take a step, try to take as few steps as possible.”

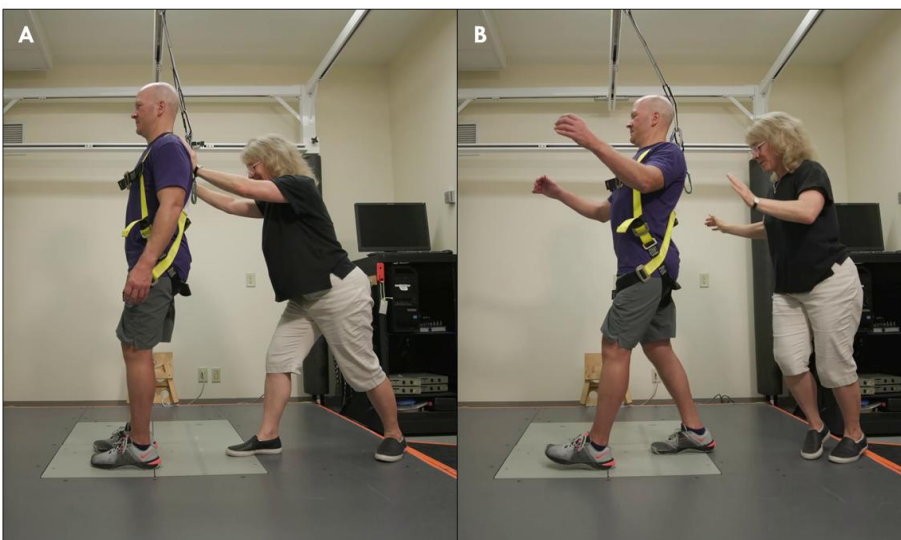


Figure 2.2. Backward-directed lean-and-release test.

Lateral direction

If the client has an asymmetrical condition (e.g., hemiparesis, lower-extremity joint replacement) start with a lean towards the less-affected side.

Stand beside the client, place one hand on the right (or left) side of the pelvis and the other hand lightly on the shoulder (make sure there is room for them to step laterally). Ask the client to lean their whole body into your hands. Ask them to lean until the midline of pelvis is over the right (or left) foot and then suddenly release your support (Figure 2.3).

Instructions to the client:

“Stand with your feet together, arms down at your sides. Lean into my hands beyond your sideways limit. When I let go, do whatever is necessary to avoid a fall. If you need to take a step, try to take as few steps as possible.”



Figure 2.3. Laterally-directed lean-and-release test.

2.3.3 Suggested modifications

- **Number of repetitions:** The Balance Evaluation Systems Test only requires one repetition of each perturbation direction. You can complete several repetitions to determine if the area of dyscontrol identified is a ‘one-off’ or more persistent.
- **Assess under other conditions, including:**
 - **Encouraged-use of non-preferred limb:** Most people have a preference for initiating stepping reactions with one limb, but should still be able to initiate the step with their non-preferred limb. However, some people, particularly those with asymmetrical conditions like stroke, are unable to take a step with both limbs. Use an obstacle or your foot to block the clients’ step with their preferred limb during forward or backward perturbations to evaluate the capacity of the non-preferred limb to respond to a loss of balance. See the toolkit videos for examples.
 - **Dual-task:** To probe ability to switch attention to recover balance, consider adding a cognitive task prior to the perturbation (e.g., counting backwards by 3s or 7s, or listing words beginning with a specified letter).

3.0 PLANNING THE PROGRAM

In this chapter

- Considerations for planning a reactive balance training program
- Recommended equipment
- Ensuring client safety during reactive balance training

3.1 RBT is just one part of a comprehensive physical rehabilitation plan

RBT is one part of the physical rehabilitation plan, which considers client's specific impairments and function, and rehabilitation goals. Depending on the clients' functional level, it may be appropriate to prescribe exercises to build strength, endurance, standing balance, walking function etc. prior to starting RBT.⁷⁶

3.2 The program is individualized to the client's specific impairments in reactive balance control

To create an effective training program, consideration is made of the client's unique areas of dyscontrol (identified on initial assessment; see Section 2.3 and Appendix 1) and functional goals. Appendix 2 outlines areas of dyscontrol and some suggested treatment approaches for each problem. The principle of individual differences considers an individual's response to exercise. Therefore, progression should be gradual, systematic, and occur at the individual client's rate of improvement. Task difficulty is not absolute and could vary from client-to-client depending on specific control problems and other deficits.

3.3 List of equipment

The following equipment is required for this specific program:

- Safety harness and overhead support system (see Section 3.5.2);
- Client-specific equipment (e.g., walking aid, ankle brace/orthosis, helmet, arm sling).
- Additional therapy equipment used for motor, cognitive, sensory, or environmental challenges (e.g., see Appendix 3).

3.4 Preparing the client

Many clients express fear and anxiety related to loss of balance during RBT.^{24,76,77} It is important to adequately prepare the client and monitor throughout. As with all interventions, informed consent is required. Given the nature of RBT, we recommend adequate explanation with a demonstration to ensure clients understand the purpose, risks, benefits, and what is expected of them during training. The client handout within this toolkit may be useful to help clients understand what is involved in RBT (see: <https://kite-uhn.com/tools/rebal>).

- Review safety considerations with the client (e.g., the harness will prevent a fall, the therapist will offer assistance if a fall into the harness is likely).
- Explain the importance of the loss of balance; that losing balance is the only way to learn to react and that it is the therapist's responsibility to ensure that the client loses their balance over and over.
- Make sure that the client understands that, as their ability to react improves, the challenge of the training will be increased. Remind the client that, if the challenge is not great enough, the training will not help the client to learn the reactive balance skills required for everyday life.
- Monitor how the client is feeling regularly throughout the treatment session.
- Reinforce with the client that they should tell you if they are experiencing any pain, discomfort or other symptoms and that they can stop the treatment or take a rest at any time should they be feeling anxious.
- Start with tasks that are predictable and less challenging to allow the client to gain some experience and comfort with the training (see information on progressions in Section 4.3.3 and the progressions video in the toolkit).

While clients may express fear and anxiety during RBT, clients and therapists report that repeatedly executing successful balance reactions during RBT with a safety harness can help to build balance confidence and reduce fear of falling.^{76–78} Clients and therapists alike report that building trust between the therapist and the client can help to assuage these fears and anxiety.^{76,77}

3.5 Ensuring safety during training

RBT involves putting clients in situations where they lose their balance. The goal is for them to practice and improve control of balance reactions, such as reactive steps. There is a chance that clients' balance reactions will not be sufficient to prevent a fall. Appropriate measures should be in place to reduce the risk of client injury during RBT, and to ensure that clients do not fall to the ground.

3.5.1 Supervision

RBT should be closely supervised by an appropriately trained regulated healthcare professional (e.g., physiotherapist), who can provide physical assistance in the event of a failure to recover balance following a balance perturbation. To optimize effectiveness of training, the therapist should aim to provide assistance only if the client is unable to recover balance independently; this ensures that the client has the opportunity to practice balance reactions unaided. See the toolkit videos for suggestion on how to provide supervision. A second 'spotter' may be required for low functioning and/or high-risk clients – ***exercise your clinical judgement at all times to avoid risk of injury to yourself or client.***

3.5.2 Safety harness & overhead support

During RBT, participants are placed in situations where they lose balance and could fall to the floor. A safety harness that is securely attached to an overhead support is required to prevent a fall. While some therapists and clients may feel comfortable doing RBT without a safety harness (e.g., with 2-person assist, in parallel bars, and/or with mats surrounding the

client), ***we do not recommend doing RBT without a safety harness***. Note that ***falling completely into the harness could cause physical discomfort, anxiety or soft tissue injury***. The ***harness should be considered a ‘last resort’***, and healthcare professionals should attempt to intervene with some assistance in the event of failed balance recovery.

The components of the safety harness system are: 1) the harness; 2) carabiner; 3) rope/line; and 4) anchor.

Harness

A good-quality full-body safety harness should be used. The harness should have the following features/characteristics:

1. Leg straps that wrap around each leg separately;
2. When the client's body weight is fully supported by the harness (e.g., if they fall and are caught by the harness), they must be upright with most of their weight supported by the leg straps. The harness must not catch clients primarily at the waist;
3. A single attachment point at the upper back (approximately between the shoulder blades) and/or a double attachment on top of both shoulders; and
4. Able to support a load of at least 3.6 kN*.⁷⁹

We have found two styles of readily available safety harness that generally meet these requirements: industrial-style fall-arrest harnesses used by people working at heights (e.g., construction workers; Figure 3.1), and harnesses used for body-weight supported gait training (Figure 3.2).

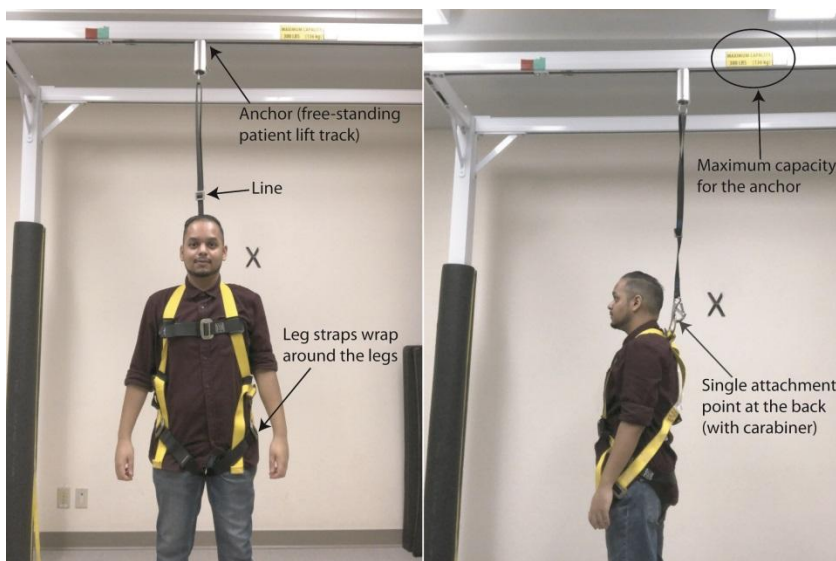


Figure 3.1: Example of an industrial harness.

* The manufacturer should indicate the maximum load (force) that the harness can withstand, expressed in Newtons (N) or kiloNewtons (kN). If gravity is the only acceleration acting on the body, then 3.6 kN is equivalent to a body mass of 367 kg (i.e., force = mass multiplied by acceleration due to gravity). However, during fall arrest, the force borne by the harness can be higher than body mass multiplied by acceleration due to gravity.

You may add temporary padding to the harness for client comfort. However, any padding must not interfere with the buckles or safe operation of the harness. DO NOT make any permanent changes to the harness (e.g., by sewing or cutting the straps).



Figure 3.2. Example of a body-weight support harness.

Industrial harnesses are designed to prevent death or serious injury in the event of a fall from a height (>3m) and comply with stringent fall-arrest standards (e.g., CSA Z259.17:16 in Canada). While these standards may be excessive for protecting against falls from a standing height, other types of harnesses are not well regulated. If you choose to use a body-weight support style harness, check with the manufacturer/supplier regarding use of the harness for fall prevention during RBT, and the maximum load that the harness can withstand. Do not use a climbing harness for RBT.

Industrial fall-arrest harnesses can be purchased from industrial suppliers and some hardware stores. Ensure that the harness meets the appropriate fall-arrest standard in your local jurisdiction (CSA Z259.17:16 in Canada). Body-weight support harnesses can be purchased from rehabilitation/medical suppliers. Both styles of harness can also be purchased from general online retailers, like Amazon; if you purchase a harness through one of these retailers, ensure that it meets relevant quality and safety standards.

Carabiner

A carabiner is a metal link with a safety closure used to attach a harness to the subject line. The carabiner must be rated to 22 kN or higher.⁷⁹ Carabiners also must have a locking mechanism to hold the opening in the closed position, such as a twisting gate or a spring loaded gate. These mechanisms ensure that you must do two actions to open them, so they will not accidentally open at the wrong time. If a carabiner can open with a single action, do not use it.

Carabiners can be purchased from industrial suppliers and sporting goods stores.

Line

A line is a flexible link between the harness and the anchor. Lines can be a fixed length via a rope, linked webbing or a metal link. Other lines can spool in and out, locking if pulled out too quickly (like a seat belt in a car). The line must be rated to 22 kN or higher.⁷⁹

Spool lines can be purchased from industrial suppliers. Ropes and linked webbing can be purchased from industrial suppliers and sporting goods stores (e.g., rope for mountain climbing).

Anchor

An anchor is the secure point for attaching the line, marked with its maximum capacity, as the “safe working load”. The safe working load is the maximum mass that can be supported under that point (i.e., the client).

The anchor can be a single point, or can be a track that allows the client to move freely around a limited space (e.g., a ceiling mounted or free-standing lift track). Check with the maintenance department at your institution and the manufacturer/supplier regarding use of the anchor for fall prevention during RBT, and the maximum load that the anchor can withstand

Correct use of the safety harness system

1. Visually inspect the safety harness, carabiner, line, and anchor prior to each use. Check for frayed edges, broken fibres, pulled stitches, cuts, burns, bent or chipped metal, torn rubber gaskets, deformation etc. There should be no knots in the line. Do not use the safety harness system if it shows any signs of wear or defect.
2. Follow the manufacturer’s instructions regarding regular replacement of the safety harness, and the maximum client weight.
3. Do not use the safety harness system with a client who exceeds the maximum weight limits of the safety harness or anchor.
4. Follow the manufacturer’s instructions regarding the correct way to don the safety harness. The harness should be fitted so that it is snug, but not so tight that it restricts movement or is unnecessarily uncomfortable.
5. Secure the harness to the line with enough slack so that it is not tugging on the client, but not so much slack that their knees can touch the ground if they fall.
6. Once secured to the line and anchor, allow the client to ‘test’ the safety harness system by asking them to gradually try to kneel down (note that they should not actually be able to kneel; see Figure 3.3).
7. There is a risk of injury to clients when they fall into the safety harness. The risk of injury is greater for more frail clients. Avoid activities where clients can vigorously and abruptly fall. Avoid situations where **all** of the clients’ body weight is supported by the safety harness after a loss of balance (i.e., their feet are off the ground). Ideally, if a client is unable to recover balance on their own, they would remain on their feet with just a portion of their body weight supported by the harness system, and a portion supported by the spotter(s).
8. Pressure from body weight being supported by the harness can restrict blood flow. Therefore, if a client falls completely into the safety harness they should not be left

supported by the harness for long. Ideally, the client would be able to immediately return to a fully upright position on their own, or with assistance from the spotter(s). If you are unable to get the client upright after a fall into the safety harness (e.g., the client loses consciousness), you should have two people support the clients' body weight while you cut the line or release the harness buckles and lower the client slowly to the floor or a chair/plinth.

9. Clean the harness between clients by following manufacturer instructions and infection control policies at your institution

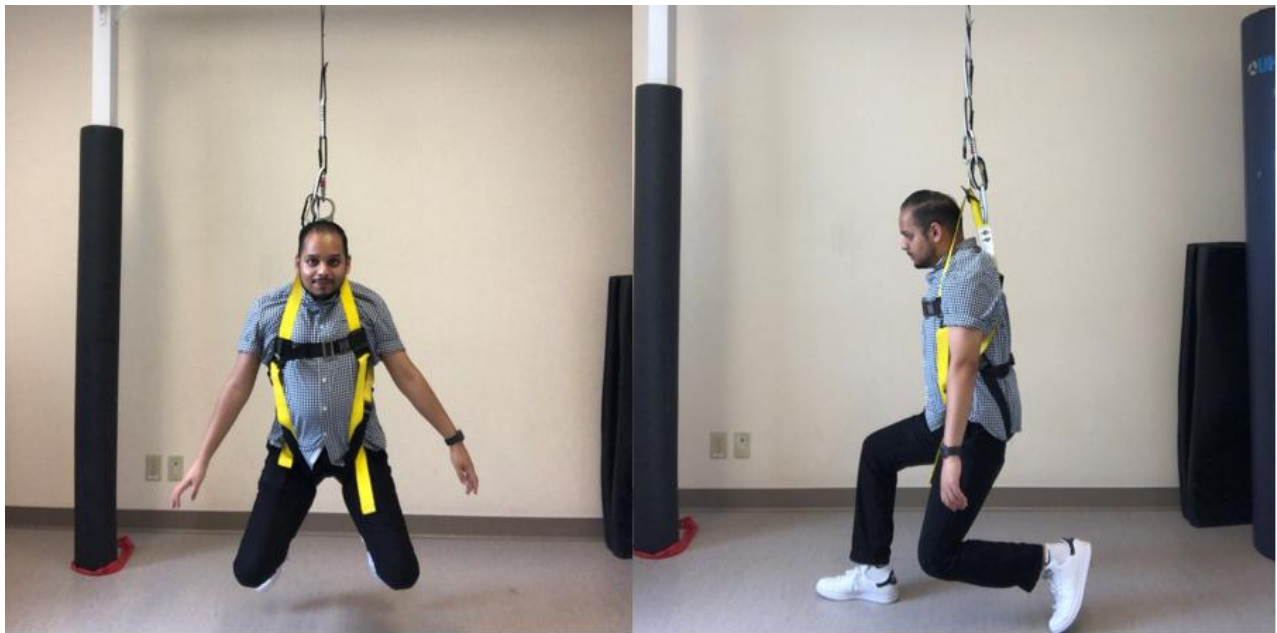


Figure 3.3: Correct use of the safety harness system. When the client's body weight is completely supported by the safety harness, their knees should not touch the ground (image on the left). To ensure that there is not too much slack in the safety harness or the line, you can ask clients to test the harness by trying to kneel down. If the participant is unable to attempt to kneel with both knees, you can ask them to try a lunge instead, and to try to lower one knee to the ground (image on the right).

It is a good idea to try the safety harness out yourself before using it with your clients to better understand how the harness feels during movement and what it feels like to be caught by the harness after a fall.

3.5.3 Protective equipment for ankle

Reactive stepping elicits responses that necessarily are much faster than voluntary steps (e.g., during walking). An ankle-foot orthosis (if prescribed) or an ankle stabilizing brace (e.g., Figure 3.4) may be required during RBT to prevent injury. Even if the client does not typically use an orthosis or brace during walking (i.e., where the individual can control the speed of their stepping), they may require an orthosis or brace during reactive stepping. Err on the side of caution.

An ankle-foot orthosis or stabilizing brace is recommended if the client meets one or more of the following criteria:

- Client typically uses an ankle-foot orthosis during home and/or community walking;

- Client does not typically use an ankle-foot orthosis but exhibits:
 - poor motor control in the foot/ankle (weakness, impaired movement, instability),
 - spasticity (e.g., risk of ankle inversion during fast movements),
 - poor ankle joint position sense,
 - poor plantar somatosensation; and/or
- The treating therapist feels this is necessary to preserve stability of the ankle joint and prevent injury.



Figure 3.4: Example of an ankle brace. The brace helps provide some lateral stability to the ankle for clients with poor ankle/foot control or sensation.

3.5.4 Additional safety equipment

Additional safety equipment may be required to prevent injury in the event of a fall or unintentional contact with surrounding structures. Clients with a cranial bone flap removed should wear a safety helmet during RBT. There should be no sharp objects in the environment that clients can contact during training. You may place padding around walls, posts, or other objects in the environment to prevent injury in the event of collision during training.

3.5.5 Other safety considerations

If you would normally measure your client's heart rate and blood pressure before exercise, you should also do so at the start of each RBT session. If heart rate and/or blood pressure are outside of an acceptable range, a second measure should be obtained. If the values continue to be outside of the range, the client should be asked to sit quietly for 5 minutes and perhaps, take a few deep breaths or drink a glass of water, before taking a third measurement. Clients with measurements outside of the acceptable range can also be questioned regarding recent medications (what they have taken and when, or if they have not taken their usual medications), when they last had something to eat/drink, and if they recently took caffeine, exercised, or smoked. The decision to continue or terminate the session is made by the therapist considering factors such as the client's usual resting heart rate or blood pressure, how far the measured values are outside of the acceptable range, the client's usual medication (e.g., beta-blockers), and the client's perception of how they are feeling. If the visit is terminated, the therapist may advise that the client follow-up with his primary care physician. The therapist may also choose to monitor heart rate and blood pressure regularly throughout the visit and observe cardiovascular responses to exercise.

4.0 IMPLEMENTATION

In this chapter

- How to provide balance perturbations for reactive balance training
- Principles of training, including client-specific adaptations and progressions
- Suggested approaches for documenting the training

4.1 Methods of perturbation

Internal perturbations happen when the client loses balance when attempting to sit or stand still or when executing a voluntary movement, like turning, reaching, or walking; there is no external force that causes the loss of balance. Even though slips and trips involve external factors (e.g., slippery floor or obstacles), they are internal perturbations because there is no external *force*, and the person misjudged how they should move or made an error in their movement that caused the loss of balance (e.g., did not lift the foot high enough in swing to avoid an obstacle). Therefore, most falls in daily life are preceded by internal perturbations.

Various voluntary tasks, including rapid ‘agility’ tasks (e.g., rapid turning or step-ups) can be used to evoke internal perturbations in RBT. Tasks like standing with eyes closed may cause an internal perturbation for a client who finds this challenging. The accompanying toolkit videos show examples of tasks that can cause internal perturbations. However, some clients are not willing to put themselves in situations that cause a loss of balance or necessitate a stepping reaction; e.g., they may choose to perform agility tasks slowly. Therefore, external perturbations can also be included in every session to ensure a sufficient training dose.

External perturbations are caused by a force outside of the client’s control, such as movement of the surface under their feet, or a push or pull. Researchers have used custom devices like moving platforms¹⁴ or pulley devices^{12,16} for external perturbations. There are also some commercially-available devices designed to provide external perturbations for RBT. Some of these devices are described in Table 4.1.

Rehabilitation therapists may not have the funding to purchase devices for RBT, space for the device, or the time to learn/set-up the device.^{76,80,81} Therefore, the following section focuses on RBT using ‘manual’ external perturbations that do not require any specialized equipment. Most of the information provided in this toolkit can still be applied to RBT using external perturbations provided by commercially-available devices. There are two methods for evoking manual external perturbations: 1) lean-and-release (predictable direction/magnitude; or 2) push/pull (can be unpredictable in terms of direction and magnitude).

Table 4.1: Commercially available device for RBT.

Name	Manufacturer	Description
ActiveStep	Simbex, Lebanon	Treadmill; antero-posterior perturbation can be provided by sudden acceleration/deceleration of the treadmill belt
Balance Tutor	MediTouch, Thuvot, Israel	Treadmill mounted on a moving platform; perturbations can be provided by sudden acceleration/deceleration of the treadmill belt (antero-posterior) or platform (medio-lateral)
Bertec Fit	Bertec, Columbus, Ohio, USA	Dual-belt treadmill; antero-posterior perturbations can be provided by sudden acceleration/deceleration of one treadmill belt
GRAIL (Gait Real-time Analysis Interactive Lab)	Motek Medical BV, Amsterdam, the Netherlands	Dual-belt treadmill mounted on a moving platform; perturbations can be provided by sudden acceleration/deceleration of one treadmill belt (antero-posterior) or translation/tilt of the moving platform
ZeroG Gait & Balance System	Aretech LLC, Sterling, USA	Pull perturbations provided by robotic overhead harness system

We do not currently know which types of perturbations (internal or external, or which type of external perturbation) are most effective for RBT. A preliminary systematic review and meta-analysis of clinical trials found some evidence that approaches using low-tech internal and manual external perturbations may be more effective than approaches using custom or commercially-available devices.⁸² However, there was a lot of variability in the training approaches used and populations studied in the trials included in the meta-analysis, which meant that definitive conclusions about the best training approach could not be made

4.2 External perturbation methods

1) Lean and release

a. Forward-directed lean-and-release perturbation. The client stands facing the therapist, leaning forward with some of his body weight supported by the therapist. He should be leaning far enough forward that his shoulders and hips are ahead of his toes; however, smaller lean angles can be used with more impaired individuals. The therapist's hands are on the clients' shoulders. At an unexpected time, the therapist releases her hands and the client starts to fall forward, requiring a step to regain stability (Figure 4.1). Expected or predictable releases may be used initially. The goal is for the client to take as few steps as possible to recover.



Figure 4.1. Forward-directed lean-and-release perturbation. The client leans forward and the therapist supports his weight (A). The therapist releases her support and the client steps to recover his balance (B).

b. Backward-directed lean-and-release perturbation. The client stands in front of and facing away from the therapist, leaning backward with some of his body weight supported by the therapist. He should be leaning far enough backward that his shoulders and hips are over or behind his heels; however, smaller lean angles can be used with more impaired individuals. The therapist's hands are on the clients' upper back. At an unexpected time, the therapist releases her hands and the client starts to fall backward, requiring a step to regain stability. Expected or predictable releases may be used initially. The goal is for the client to take as few steps as possible to recover upright standing balance.



Figure 4.2. Backward-directed lean-and-release perturbation. The client leans backward and the therapist supports his weight (A). The therapist releases her support and the client steps to recover his balance (B).

c. Lateral-directed lean-and-release perturbation. The client stands with his feet close together, leaning to the right (or left) with some of his body weight supported by the therapist's hands. He should be leaning far enough to the right (or left) that the midline of the pelvis is aligned over the right (or left) foot; however, smaller lean angles can be used with more impaired individuals. The therapist's hands are on the client's right (or left) shoulder and right (or left) hip. At an unexpected time, the therapist releases her hands and

the client starts to fall to the right (or left), requiring a step to regain stability. The goal is for the client to take as few steps as possible to recover balance.



Figure 4.3. Lateral-directed lean-and-release perturbation. The client leans to the left and the therapist supports his weight (A). The therapist releases her support and the client steps to recover his balance (B).

2) Multi-directional push/pull

a. Multidirectional push. The therapist places her hands on the client's hips or shoulders and pushes him forward (or sideways), requiring a reactive step to regain stability. Alternatively, one of the therapist's hands could be on the hip and the other on the shoulder; a push forward at the level of one scapula would facilitate a diagonal reactive step. In all scenarios, the therapist should be ready to assist with the recovery, if necessary, by having a light hold of the safety harness. The therapist should only provide assistance if the client is unable to regain stability independently; this is true with every reaction. Note that **backward-directed pushes are not performed** as the therapist would not be in a position to assist with recovery should the client start to fall.

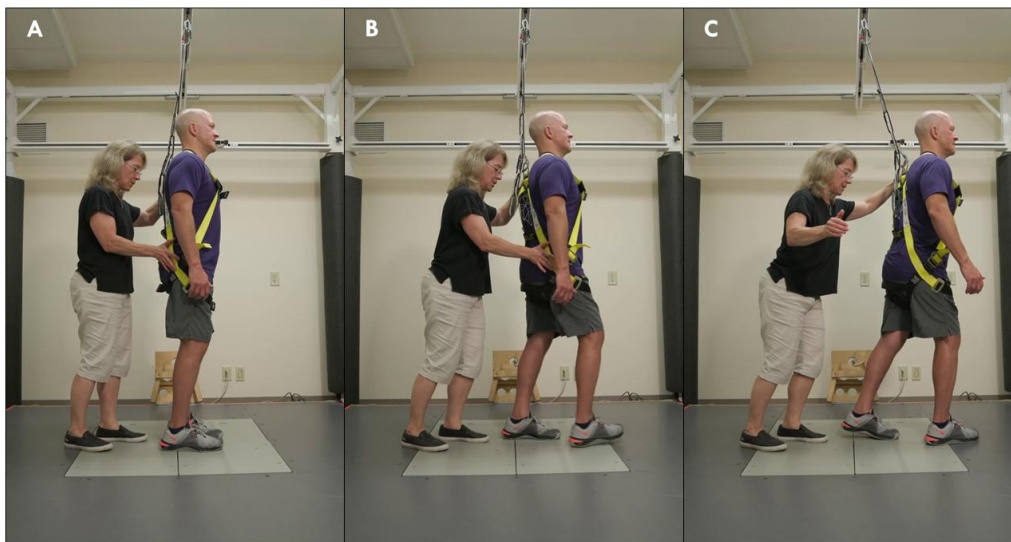


Figure 4.4. Forward-directed push perturbation. The therapists' hands may be placed at the hips or with one hand on the hips and one on the shoulders (A & B).



Figure 4.5. Lateral-directed push perturbation. The therapist places her hands on the client's right (or left) hip or shoulder and pushes him to the left (or right), requiring a reactive step to regain stability.

b. Multi-directional pull perturbation. The therapist may pull the client's shoulders or hips, or pull on the harness to cause the client to start to fall, requiring a reactive step to regain stability. Avoid applying pull perturbations to the shoulder if the client has a subluxed or flaccid shoulder.

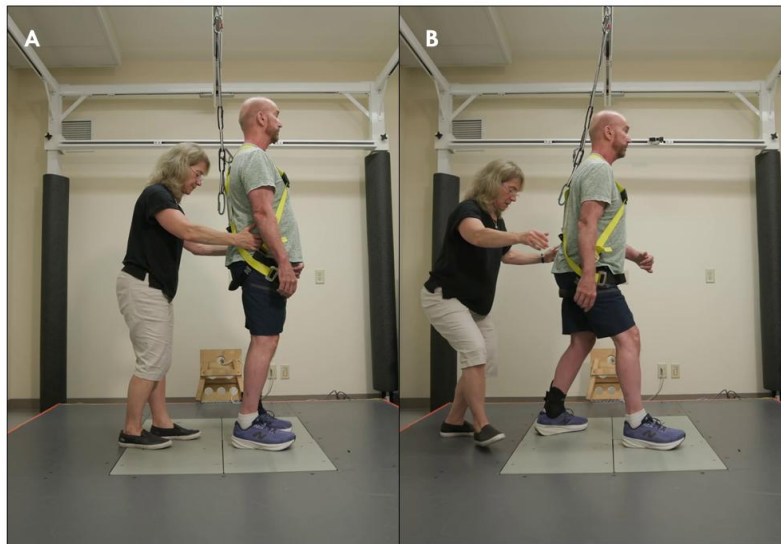


Figure 4.6. Backward-directed pull perturbation. The therapist uses the shoulders, hips, or harness to pull the client backward, requiring a reactive step to regain stability.

4.3 Training principles

The following training principles are specific to RBT. Additional interventions and training strategies may be warranted to address underlying impairments that contribute to impaired anticipatory or reactive balance control (e.g., strength training).

4.3.1 The balance challenge should be greater than that experienced in daily life and during 'traditional' exercise

While individuals may experience some balance perturbations during daily life, the number and magnitude of perturbations during RBT should be greater than that experienced under

typical circumstances. The perturbations themselves have to be **intense** enough to elicit stepping responses. It is important to allow for success, which is defined as independent recovery of balance with a response of 2 steps or less, some of the time. The rest of the time the perturbations should require a multistep reaction or need for assistance. Overall, the client needs to lose balance and the goal is to regain, rather than to maintain balance.

4.3.2 The program should be specific to the clients' problems with balance control

The RBT program must incorporate activities that evoke balance reactions. The client-specific training program should: 1) have specific focus on client's goals and expectations for recovery and community ambulation; 2) target client-specific problems with reactive balance control (see Table 2.2 and Appendix 2); and 3) target specific impairments in reactive balance control that could place the client at increased risk of falls (Table 2.2).

Table 4.2: Recommended frequency, intensity, time and type of reactive balance training.

Note that optimal parameters are not known yet. Studies in apparently healthy older adults provide evidence that a single session of RBT with 24 repetitions is sufficient to improve reactive balance control and prevent falls.^{83,84}

Frequency	1-2 sessions/week
Intensity	Sufficient perturbation magnitude to elicit a reactive step Not such a large magnitude that clients 'fall' (into the safety harness) all the time
Time	≥24 repetitions per session ⁸⁴
Type	See Section 4.2 (Methods of perturbation) Include a variety of perturbations and tasks

4.3.3 As clients adapt and improve, the level of challenge should increase

Small-magnitude external perturbations may be used with clients who have lower functional abilities. It is usually easiest to start with perturbations that cause a fall towards the therapist (i.e., pull or lean-and-release) so that the therapist can control the outcome and alleviate clients' anxiety and facilitate clients' perceptions of safety. The difficulty of the balance challenge should be progressed in order to achieve the desired intensity. Client-specific progression can be made by manipulating the motor task, sensory condition, cognitive requirements, or environment, or increasing the magnitude of external perturbations. See the accompanying videos for suggested ways to progress the intensity of training. Clients should be allowed to progress at their own pace.

If a client expresses fear or anxiety related to the perturbations, you should start with 'easier' perturbations (e.g., internal perturbations, small magnitude, cued/predictable perturbations). Gradually increase the difficulty of the perturbations as the client gets used to the training (see Section 3.4).



Progressions

Perturbation type	<ul style="list-style-type: none"> Lean/pull toward → Push away
Perturbation magnitude	<ul style="list-style-type: none"> Small → Large
Perturbation direction	<ul style="list-style-type: none"> Forward → Lateral → Backward* Predictable → Unpredictable
Perturbation timing	<ul style="list-style-type: none"> Cued → Unpredictable
Other challenges	<ul style="list-style-type: none"> Motor tasks Sensory (eyes closed/dim lights, stand on foam) Cognitive tasks Environmental

*May be client dependent; e.g., clients with hemiparesis may find lateral perturbations or challenging than backward perturbations.

4.3.4 Short-term adaptation might not indicate long-term learning.

Consistent with motor learning research⁸⁵ apparent improvements in balance control within a session might not be retained long-term. Changes to the training program based on these apparent short-term improvements should not be made. Instead, the therapist should assess whether these improvements are retained in the next training session before making changes.

4.3.5 Consider incorporating variability in training parameters

Each training session should eventually require the client to react to a variety of different perturbation conditions. The following training parameters can be varied: 1) direction of perturbation (forward, backward, lateral, diagonal); 2) magnitude of perturbation; 3) type of perturbation (i.e., internal vs. external); 4) perturbation timing (e.g., cued versus unpredictable) and 5) additional motor, cognitive, sensory, or environmental challenges. Ideally, training parameters will be varied trial-to-trial, but it is not necessary to vary all parameters trial-to-trial. If trial-to-trial variability is not feasible then parameters may be varied in blocks. Perturbation trials should be included with non-perturbation trials to prevent anticipation or pre-planning of responses.

Variability and random presentation of tasks **may depend on the stage of learning**. Clients who are earlier in the RBT training program may benefit from tasks that are consistent from trial-to-trial, and perturbation characteristics that are more predictable until they begin to have some success in executing the desired stepping reactions. As clients improve their balance control and confidence, more variable and unpredictable tasks can be included.

4.3.6 Support should be minimal

The safety harness should not support clients, unless they are unable to recover balance using their own reactions or from therapist assistance (Figure 3.3). Therapists should use clinical judgement to ensure the provision of adequate supervision and ability to provide physical assistance if required, while also allowing clients to attempt to regain balance

without providing assistance prematurely (see the accompanying videos for more information).

4.3.7 Both verbal instruction and demonstration may be useful

Instruction should refer to the whole task, rather than part of a task (e.g., do not provide instructions regarding specific movement patterns). Instructions should be simple with just one instruction given at a time.

4.3.8 Promote an external focus of attention

Clients should be encouraged to focus on the effects of their movement rather than a specific movement pattern. Feedback and instructions should promote an external focus of attention. It may be useful to change the environment to achieve specific goals of training rather than providing instructions/feedback to focus on specific movement pattern; e.g., place an obstacle on the ground as a target to step over to encourage increased step length or limb clearance.

4.3.9 When to stop RBT

Some clients might not improve reactive balance control with RBT. We do not yet understand what factors determine if a client will or will not respond to RBT. Regularly assessing reactive balance control (see Section 2.3) can help determine if your client is improving. If a client does not appear to improve after repeated sessions, you could consider discontinuing RBT and focusing therapy time on other aspects of balance and mobility. Likewise, you should stop RBT if a client reaches a plateau or ceiling in reactive balance control; that is, if they improved initially but are no longer improving with repeated sessions, or if they are consistently able to respond to large magnitude perturbations in multiple directions with a single step.

4.4 Documentation

Documentation of balance training sessions should focus on: 1) client-specific problems; 2) ongoing progression; and 3) client safety. The Reactive Balance Training Log (Appendix 4) can be used to document the following:

- Performance on reactive stepping linked to key areas of focus (e.g., if a goal is to reduce frequency of multiple stepping then frequency of multiple stepping should be documented);
- Number of repetitions (i.e., number of times the client experiences a loss of balance)
- Balance reactions (i.e., balance recovered independently using 2 steps or fewer; balance recovered using more than 2 steps; or assistance provided by the safety harness or therapist to recover balance);
- Additional tasks/conditions;
- Number of rest breaks;
- Client's perceived intensity of balance training (see below and Appendix 5); and
- Heart rate and/or blood pressure (if indicated).

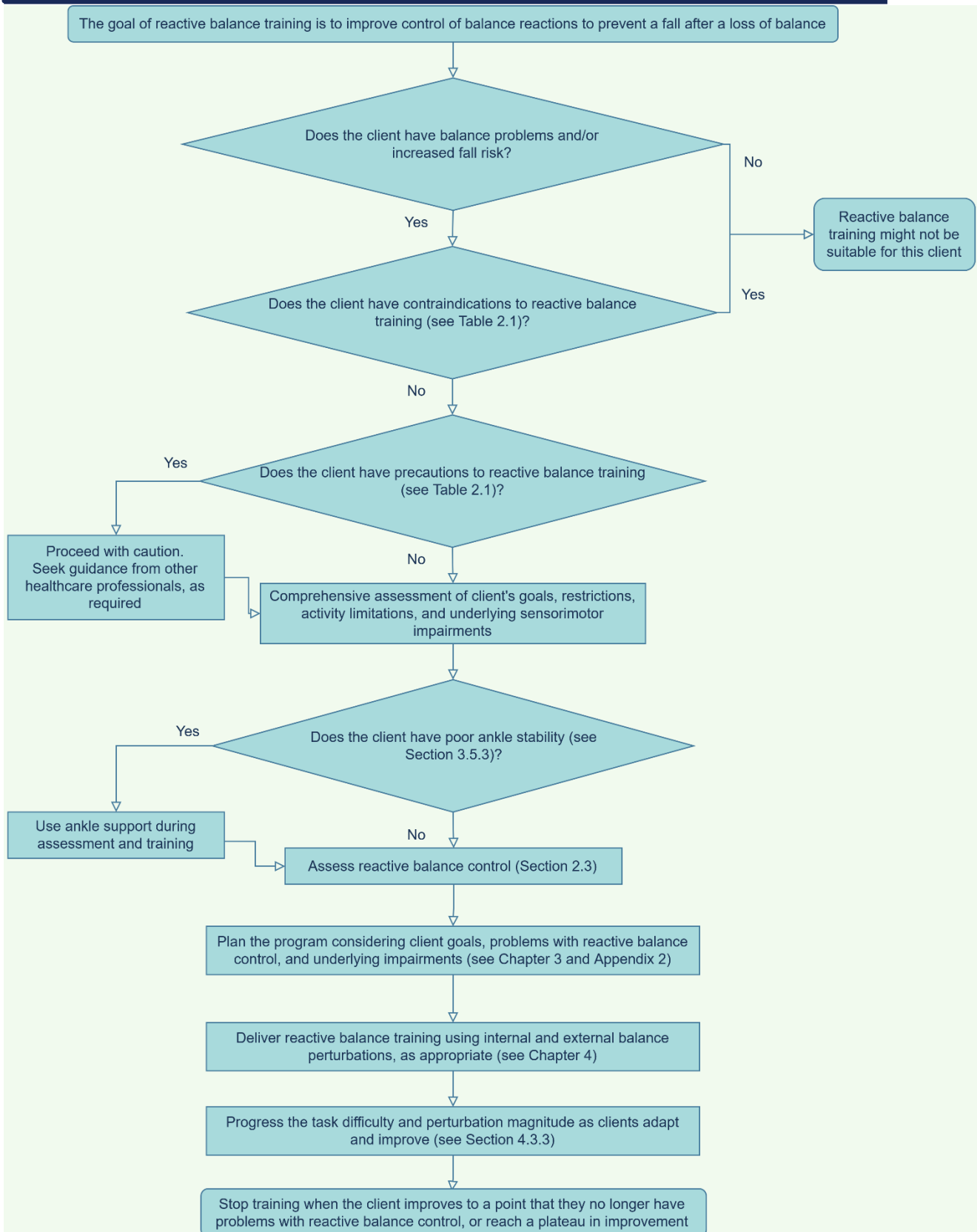
The training log in Appendix 4 is provided as a suggested way to document training sessions. Use of this specific training log might not be compatible with health record keeping at your institution/organization. You might prefer to use another method to document RBT sessions.

There are a few rating scales available to allow clients to rate their perceived intensity, or level of challenge/difficulty, of balance training. These scales are included in Appendix 5.

1. The OMNI Perceived Exertion Scale is a generic scale used to rate perceived exertion of any type of exercise.⁸⁶ Clients rate their perceived exertion on a scale from 0-10. OMNI Perceived Exertion Scale scores correlate with challenge of anticipatory⁸⁷ and reactive⁸⁸ balance training.
2. The Rate of Perceived Stability scale is a balance-training specific scale that asks clients to rate their perceived stability on a scale from 0-10.⁸⁹ The Rate of Perceived Stability scale is a valid measure of intensity of anticipatory balance training.⁸⁷ As the goal of RBT is to evoke balance reactions, but not falls, you should aim for scores of 9-10 when using this scale in RBT.
3. The Balance Intensity Scale asks clients to score effort during balance training on a scale from 1-5.⁹⁰ Balance Intensity Scale scores correlate with challenge of anticipatory⁹⁰ and reactive⁸⁸ balance training.

5.0

SUMMARY FLOWCHART



REFERENCES

1. Hyndman D, Ashburn A, Stack E. Fall events among people with stroke living in the community: circumstances of falls and characteristics of fallers. *Arch Phys Med Rehabil*. 2002;83(2):165-170. doi:10.1053/apmr.2002.28030
2. Maki BE, McIlroy WE. Postural control in the older adult. Studenski S, ed. *Clin Geriatr Med*. 1996;12(4):635-658.
3. Shumway-Cook A, Woollacott MH. *Motor Control: Translating Research into Clinical Practice*. 4th ed. Wolters Kluwer Health/Lippincott Williams & Wilkins; 2012.
4. Maki BE, McIlroy WE. The role of limb movements in maintaining upright stance: the “change-in-support” strategy. *Phys Ther*. 1997;77:488-507.
5. Mansfield A, Inness EL, McIlroy WE. Stroke. In: Day BL, Lord SR, eds. *Handbook of Clinical Neurology: Balance, Gait, and Falls*. Vol 159. Elsevier BV; 2018:205-228.
6. Pai YC, Bhatt TS. Repeated-slip training: an emerging paradigm for prevention of slip-related falls among older adults. *Phys Ther*. 2007;87(11):1478-1491. doi:10.2522/ptj.20060326
7. Chmielewski TL, Hurd WJ, Rudolph KS, Axe MJ, Snyder-Mackler L. Perturbation training improves knee kinematics and reduces muscle co-contraction after complete unilateral anterior cruciate ligament rupture. *Phys Ther*. 2005;85(8):740-749. doi:10.1093/ptj/85.8.740
8. Mansfield A, Peters AL, Liu BA, Maki BE. Effect of a perturbation-based balance training program on compensatory stepping and grasping reactions in older adults: a randomized controlled trial. *Phys Ther*. 2010;90(4):476-491. doi:10.2522/ptj.20090070
9. Nørgaard JE, Andersen S, Ryg J, et al. Effect of treadmill perturbation-based balance training on fall rates in community-dwelling older adults: a randomized clinical trial. *JAMA Netw Open*. 2023;6(4):e238422.
10. Batcir S, Gimmon Y, Kurz I, et al. Effect of surface perturbation treadmill training program on strategies and kinematics of reactive stepping during standing in older adults: a single-blinded randomized controlled trial. *Gerontology*. 2025;71(6):439-452. doi:10.1159/000545480
11. Parijat P, Lockhart TE. Effects of moveable platform training in preventing slip-induced falls in older adults. *Ann Biomed Eng*. 2012;40(5):1111-1121. doi:10.1007/s10439-011-0477-0
12. Rogers MW, Creath RA, Gray V, et al. Comparison of lateral perturbation-induced step training and hip muscle strengthening exercise on balance and falls in community-dwelling older adults: a blinded randomized controlled trial. *J Gerontol A Biol Sci Med Sci*. 2021;76(9):e194-202.
13. Shen X, Mak MKY. Technology-assisted balance and gait training reduces falls in patients with Parkinson’s disease: a randomized controlled trial with 12-month follow-up. *Neurorehabil Neural Repair*. 2015;29(2):103-111. doi:10.1177/1545968314537559
14. Ribeiro de Souza C, Avila de Oliveira J, Takazono PS, et al. Perturbation-based balance training leads to improved reactive postural responses in individuals with Parkinson’s disease and freezing of gait. *Eur J Neurosci*. 2023;57(12):2174-2186. doi:https://dx.doi.org/10.1111/ejn.16039

15. Aviles J, Allin LJ, Alexander NB, Van Mullekom J, Nussbaum MA, Madigan ML. Comparison of treadmill trip-like training versus Tai Chi to improve reactive balance among independent older adult residents of senior housing: a pilot controlled trial. *J Gerontol A Biol Sci Med Sci*. 2019;74(9):1497-1503. doi:10.1093/gerona/glz018
16. Monjezi S, Molhemi F, Shaterzadeh-Yazdi MJ, et al. Perturbation-based balance training to improve postural responses and falls in people with multiple sclerosis: a randomized controlled trial. *Disabil Rehabil*. 2023;45(22):3649-3655. doi:10.1080/09638288.2022.2138570
17. Mansfield A, Aquil A, Danells CJ, et al. Does perturbation-based balance training prevent falls among individuals with chronic stroke? A randomised controlled trial. *BMJ Open*. 2018;8(8):e021510. doi:10.1136/bmjopen-2018-021510
18. Marigold DS, Eng JJ, Dawson AS, Inglis JT, Harris JE, Gylfadóttir S. Exercise leads to faster postural reflexes, improved balance and mobility, and fewer falls in older persons with chronic stroke. *J Am Geriatr Soc*. 2005;53:416-423. doi:10.1111/j.1532-5415.2005.53158.x
19. Handelzalts S, Kenner-Furman M, Gray G, Soroker N, Shani G, Melzer I. Effects of perturbation-based balance training in subacute persons with stroke: a randomized controlled trial. *Neurorehabil Neural Repair*. 2019;33(3):213-224. doi:10.1177/1545968319829453
20. Mansfield A, Peters AL, Liu BA, Maki BE. A perturbation-based balance training program for older adults: study protocol for a randomised controlled trial. *BMC Geriatr*. 2007;7:12. doi:10.1186/1471-2318-7-12
21. Gaßner H, Steib S, Klamroth S, et al. Perturbation treadmill training improves clinical characteristics of gait and balance in Parkinson's disease. *J Parkinsons Dis*. 2019;9(2):413-426. doi:10.3233/jpd-181534
22. Bhatt T, Yang F, Pai YC. Learning to resist gait-slip falls: long-term retention in community-dwelling older adults. *Arch Phys Med Rehabil*. 2012;93(4):557-564. doi:10.1016/j.apmr.2011.10.027
23. Inness EL, Mansfield A, Biasin L, Brunton K, Bayley MT, McIlroy WE. Clinical implementation of a reactive balance control assessment in a sub-acute stroke patient population using a "lean-and-release" methodology. *Gait & Posture*. 2015;41(2):529-534. doi:10.1016/j.gaitpost.2014.12.005
24. Devasahayam AJ, Farwell K, Lim B, et al. The effect of reactive balance training on falls in daily life: an updated systematic review and meta-analysis. *Phys Ther*. 2023;103(1). doi:10.1093/ptj/pzac154
25. Rieger MM, Papegaaij S, Steenbrink F, Van Dieën JH, Pijnappels M. Effects of perturbation-based treadmill training on balance performance, daily life gait, and falls in older adults: REACT randomized controlled trial. *Phys Ther*. 2024;104(1):pzad136. doi:10.1093/ptj/pzad136
26. Okubo Y, Sturnieks DL, Brodie MA, Duran L, Lord SR. Effect of reactive balance training involving repeated slips and trips on balance recovery among older adults: a blinded randomized controlled trial. *J Gerontol A Biol Sci Med Sci*. 2019;74(9):1489-1496. doi:10.1093/gerona/glz021
27. Batcir S, Livne K, Lehman RL, et al. Feedback-based perturbation balance training during stationary cycling improves reactive and proactive balance among older

- adults: a single-blinded randomised controlled trial. *Age Ageing*. 2025;54(8):afaf215. doi:10.1093/ageing/afaf215
28. Okubo Y, Mohamed Suhaimy MSB, Hoang P, et al. Training reactive balance using trips and slips in people with multiple sclerosis: A blinded randomised controlled trial. *Mult Scler Relat Disord*. 2023;73:104607. doi:10.1016/j.msard.2023.104607
 29. Schinkel-Ivy A, Huntley AH, Aquil A, Mansfield A. Does perturbation-based balance training improve control of reactive stepping in individuals with chronic stroke? *J Stroke Cerebrovasc Dis*. 2019;28(4):935-943. doi:10.1016/j.jstrokecerebrovasdis.2018.12.011
 30. Smania N, Corato E, Tinazzi M, et al. Effect of balance training on postural instability in patients with idiopathic Parkinson's disease. *Neurorehabil Neural Repair*. 2010;24(9):826-834. doi:10.1177/1545968310376057
 31. Zhu RTL, Schulte FA, Singh NB, Ma CZH, Easthope CA, Ravi DK. Effects of single-session perturbation-based balance training with progressive intensities on resilience and dynamic gait stability in healthy older adults. *Front Bioeng Biotechnol*. 2025;13:1642158. doi:10.3389/fbioe.2025.1642158
 32. Rieger MM, Papegaaij S, Pijnappels M, Steenbrink F, van Dieen JH. Transfer and retention effects of gait training with anterior-posterior perturbations to postural responses after medio-lateral gait perturbations in older adults. *Clin Biomech*. 2020;75:104988. doi:10.1016/j.clinbiomech.2020.104988
 33. Kurz I, Gimmon Y, Shapiro A, Debi R, Snir Y, Melzer I. Unexpected perturbations training improves balance control and voluntary stepping times in older adults - a double blind randomized control trial. *BMC Geriatr*. 2016;16:58.
 34. Nørgaard JE, Andersen S, Ryg J, et al. Perturbation-based balance training of older adults and effects on physiological, cognitive and sociopsychological factors: a secondary analysis from a randomised controlled trial with 12-month follow-up. *BMJ Open*. 2024;14(8):e080550. doi:10.1136/bmjopen-2023-080550
 35. Unger J, Chan K, Lee JW, et al. The effect of perturbation-based balance training and conventional intensive balance training on reactive stepping ability in individuals with incomplete spinal cord injury or disease: a randomized clinical trial. *Front Neurol*. 2021;12:620367. doi:10.3389/fneur.2021.620367
 36. Steib S, Klamroth S, Gaßner H, et al. Exploring gait adaptations to perturbed and conventional treadmill training in Parkinson's disease: time-course, sustainability, and transfer. *Hum Mov Sci*. 2019;64:123-132. doi:10.1016/j.humov.2019.01.007
 37. Klamroth S, Steib S, Gaßner H, et al. Immediate effects of perturbation treadmill training on gait and postural control in patients with Parkinson's disease. *Gait Posture*. 2016;50:102-108. doi:10.1016/j.gaitpost.2016.08.020
 38. Steib S, Klamroth S, Gaßner H, et al. Perturbation during treadmill training improves dynamic balance and gait in Parkinson's disease: a single-blind randomized controlled pilot trial. *Neurorehabil Neural Repair*. 2017;31(8):758-768. doi:10.1123/jpah.10.3.359
 39. Esmaeili V, Juneau A, Dyer JO, et al. Intense and unpredictable perturbations during gait training improve dynamic balance abilities in chronic hemiparetic individuals: a randomized controlled pilot trial. *J Neuroeng Rehabil*. 2020;17:79. doi:10.1186/s12984-020-00707-0

40. Lanza MB, Fujimoto M, Magder L, McCombe-Waller S, Rogers MW, Gray VL. Is lateral external perturbation training more beneficial for protective stepping responses than voluntary stepping training in stroke? A pilot randomized control study. *J NeuroEngineering Rehabil.* 2024;21(1):199. doi:10.1186/s12984-024-01495-7
41. Devasahayam AJ, Barzideh A, Jagroop D, et al. The effects of reactive balance training on cardiorespiratory fitness and muscle strength: a pilot randomized controlled trial. *medRxiv.* Preprint posted online December 16, 2024. doi:10.1101/2024.12.16.24319109
42. Rogers MW, Hedman LD, Johnson ME, Martinez KM, Mille ML. Triggering of protective stepping for the control of human balance: age and contextual dependence. *Cogn Brain Res.* 2003;16:192-198.
43. Shimada H, Obuchi S, Furuna T, Suzuki T. New intervention program for preventing falls among frail elderly people: the effects of perturbed walking exercise using a bilateral separated treadmill. *Am J Phys Med Rehabil.* 2004;83:493-499.
44. Shen X, Mak MKY. Repetitive step training with preparatory signals improves stability limits in patients with Parkinson's disease. *J Rehabil Med.* 2012;44:944-949. doi:10.2340/16501977-1056
45. Okubo Y, Phu S, Chaplin C, et al. Perturbation-based balance training using trips and slips can reduce fall injuries in older adults: the SafeTrip randomised controlled trial. *medRxiv.* Preprint posted online February 23, 2026. doi:10.64898/2026.02.20.26346756
46. Fan S, Ma Y, Pan Y. Stroke patient rehabilitation: an analysis of the effects of perturbation training combined with hip unloading gait strategies. *Front Neurol.* 2025;16:1495071. doi:10.3389/fneur.2025.1495071
47. Brüll L, Hezel N, Arampatzis A, Schwenk M. Comparing the effects of two perturbation-based balance training paradigms in fall-prone older adults: a randomized controlled trial. *Gerontology.* 2023;69(7):910-922. doi:10.1159/000530167
48. Schlenstedt C, Paschen S, Kruse A, Raethjen J, Weisser B, Deuschl G. Resistance versus balance training to improve postural control in Parkinson's disease: a randomized rater blinded controlled study. *PLoS ONE.* 2015;10(10):e0140584.
49. Gandolfi M, Geroïn C, Dimitrova DM, et al. Virtual reality telerehabilitation for postural instability in Parkinson's disease: a multicenter, single-blind, randomized, controlled trial. *Biomed Res Int.* 2017;2017:7962826.
50. Rogge AK, Hötting K, Nagel V, Zech A, Hölig C, Röder B. Improved balance performance accompanied by structural plasticity in blind adults after training. *Neuropsychologia.* 2019;129:318-330. doi:10.1016/j.neuropsychologia.2019.04.005
51. Suteerawattananon M, MacNeill B, Protas EJ. Supported treadmill training for gait and balance in a patient with progressive supranuclear palsy. *Phys Ther.* 2002;82(5):485-495.
52. Woollacott M, Shumway-Cook A, Hutchinson S, Ciol M, Price R, Kartin D. Effect of balance training on muscle activity used in recovery of stability in children with cerebral palsy: a pilot study. *Dev Med Child Neurol.* 2005;47(7):455-461. doi:10.1111/j.1469-8749.2005.tb01171.x
53. Shumway-Cook A, Hutchinson S, Kartin D, Price R, Woollacott M. Effect of balance training on recovery of stability in children with cerebral palsy. *Dev Med Child Neurol.* 2003;45:591-602.

54. Bar-Haim S, Harries N, Hutzler Y, Belokopytov M, Dobrov I. Training to walk amid uncertainty with Re-Step: measurements and changes with perturbation training for hemiparesis and cerebral palsy. *Disabil Rehabil Assist Technol*. 2013;8(5):417-425. doi:10.3109/17483107.2012.754954
55. Kaufman KR, Wyatt MP, Sessoms PH, Grabiner MD. Task-specific fall prevention training is effective for warfighters with transtibial amputation. *Clin Orthop Relat Res*. 2014;472:3076-3084. doi:10.1007/s11999-014-3664-0
56. Halvarsson A, Franzén E, Farén E, Olsson E, Oddsson L, Ståhle A. Long-term effects of new progressive group balance training for elderly people with increased risk of falling - a randomized controlled trial. *Clin Rehabil*. 2013;27(5):450-458. doi:10.1177/0269215512462908
57. Robinovitch S. Ecology of falls. In: Day BL, Lord SR, eds. *Handbook of Clinical Neurology: Balance, Gait, and Falls*. Vol 159. Elsevier B.V.; 2018:147-154.
58. Andreoli A, Bianchi A, Campbell A, Bernhardt J, Bayley M, Guo M. In defence of falling: the onomastics and ethics of “therapeutic” falls in rehabilitation. *Disabil Rehabil*. 2023;45(22):3783-3787. doi:10.1080/09638288.2022.2135777
59. American College of Sports Medicine. *ACSM’s Guidelines for Exercise Testing and Prescription*. 11th ed. Wolters Kluwer; 2021.
60. Powell LE, Myers AM. The Activities-specific Balance Confidence (ABC) Scale. *J Gerontol A Biol Sci Med Sci*. 1995;50A(1):M28-34. doi:10.1093/gerona/50a.1.m28
61. Jacobs JV, Horak FB, Tran VK, Nutt JG. An alternative clinical postural stability test for patients with Parkinson’s disease. *J Neurol*. 2006;253(11):1404-1413. doi:10.1007/s00415-006-0224-x
62. Frachignoni F, Horak F, Godi M, Nardone A, Giordani A. Using psychometric techniques to improve the balance evaluation systems test: the mini-BEStest. *J Rehabil Med*. 2010;42(4):323-331. doi:10.2340/16501977-0537
63. Horak FB, Wrisley DM, Frank J. The balance evaluation systems test (BEStest) to differentiate balance deficits. *Phys Ther*. 2009;89(5):484-498. doi:10.2522/ptj.20080071
64. Mansfield A, Inness EL, Wong JS, Fraser JE, McIlroy WE. Is impaired control of reactive stepping related to falls during inpatient stroke rehabilitation? *Neurorehabilitation and Neural Repair*. 2013;27(6):526-533. doi:10.1177/1545968313478486
65. Jacobs JV, Earhart GM, McNeely ME. Can postural instability tests improve the prediction of future falls in people with Parkinson’s disease beyond knowing existing fall history? *J Neurol*. 2016;263(1):133-139. doi:10.1007/s00415-015-7950-x
66. Maki BE, Edmondstone MA, Perry SD, Heung E, Quant S, McIlroy WE. Control of rapid limb movements for balance recovery: do age-related changes predict falling risk? In: Duysens J, Smits-Engelsman BCM, Kingma H, eds. *Control of Posture and Gait*. International Society for Posture and Gait Research; 2001:126-129.
67. Hilliard MJ, Martinez KM, Janssen I, et al. Lateral balance factors predict future falls in community-living older adults. *Arch Phys Med Rehabil*. 2008;89(9):1708-1713. doi:10.1016/j.apmr.2008.01.023
68. Okubo Y, Schoene D, Caetano MJ, et al. Stepping impairment and falls in older adults: a systematic review and meta-analysis of volitional and reactive step tests. *Ageing Res Rev*. 2021;66:101238. doi:10.1016/j.arr.2020.101238

69. Mille ML, Johnson-Hilliard M, Martinez KM, Zhang Y, Edwards BJ, Rogers MW. One step, two steps, three steps more...directional vulnerability to falls in community-dwelling older people. *J Gerontol A Biol Sci Med Sci*. 2013;68(12):1540-1548. doi:10.1093/gerona/glt062
70. Carty CP, Cronin NJ, Nicholson D, et al. Reactive stepping behaviour in response to forward loss of balance predicts future falls in community-dwelling older adults. *Age Ageing*. 2015;44(1):109-115. doi:doi: 10.1093/ageing/afu054
71. Sturnieks DL, Menant J, Delbaere K, et al. Force-controlled balance perturbations associated with falls in older people: a prospective cohort study. *PLoS One*. 2013;8(8):e70981. doi:10.1371/journal.pone.0070981.t002
72. Crenshaw JR, Bernhardt KA, Atkinson EJ, et al. Posterior single-stepping thresholds are prospectively related to falls in older women. *Aging Clin Exp Res*. 2020;32(12):2507-2515. doi:10.1007/s40520-020-01480-9
73. Van Liew C, Huisinga JM, Peterson DS. Evaluating the contribution of reactive balance to prediction of fall rates cross-sectionally and longitudinally in persons with multiple sclerosis. *Gait Posture*. 2022;92:30-35. doi:10.1016/j.gaitpost.2021.11.008
74. Mansfield A, Wong JS, McIlroy WE, et al. Do measures of reactive balance control predict falls in people with stroke returning to the community? *Physiotherapy*. 2015;101(4):373-380. doi:10.1016/j.physio.2015.01.009
75. Inness EL, Mansfield A, Bayley M, McIlroy WE. Reactive stepping after stroke: determinants of time to foot off in the paretic and non-paretic limbs. *J Neurol Phys Ther*. 2016;40(3):196-202.
76. Jagroop D, Houvardas S, Danells CJ, et al. Rehabilitation clinicians' perspectives of reactive balance training. *Disabil Rehabil*. 2022;44(25):7967-7973. doi:10.1080/09638288.2021.2004246
77. Unger J, Singh H, Mansfield A, Masani K, Musselman KE. The experiences of people with incomplete spinal cord injury or disease during intensive balance training and the impact of the program: A qualitative study. *Spinal Cord*. 2022;60(12):1062-1068. doi:10.1038/s41393-022-00823-9
78. Pak P, Lamb B, Tirone C, et al. Incorporating research technology into the clinical assessment of balance and mobility: perspectives of physiotherapists and patients with stroke. In: 2013.
79. CSA Group. *Selection and Use of Active Fall-Protection Equipment and Systems*. CSA Group; 2020.
80. Mansfield A, Danells CJ, Inness EL, Musselman KE, Salbach NM. A survey of Canadian healthcare professionals' practices regarding reactive balance training. *Physiother Theory Pract*. 2021;37(7):787-800. doi:10.1080/09593985.2019.1650856
81. Ogonowska-Slodownik A, Faria JO, Tokarska J, Mansfield A. Professional education and clinical application of balance control and reactive balance training: a cross-sectional national survey of Polish healthcare professionals. *BMC Med Educ*. 2025;25(1):1459. doi:10.1186/s12909-025-08030-9
82. Nachmani H, Langer LK, Devasahayam AJ, Mansfield A. Influence of reactive balance training program characteristics on reactive balance control and fall risk: a systematic review and meta-analysis. *medRxiv*. Preprint posted online August 5, 2025. doi:10.1101/2025.08.01.25332828

83. Pai YC, Yang F, Bhatt T, Wang E. Learning from laboratory-induced falling: long-term motor retention among older adults. *Age (Dordr)*. 2014;36(3):9640. doi:10.1007/s11357-014-9640-5
84. Pai YC, Bhatt T, Yang F, Wang E. Perturbation training can reduce community-dwelling older adults' annual fall risk: a randomized controlled trial. *J Gerontol A Biol Sci Med Sci*. 2014;69(12):1586-1594. doi:10.1093/gerona/glu087
85. Schmidt RA, Bjork RA. New conceptualizations of practice: common principles in three paradigms suggest new concepts for training. *Psychol Sci*. 1992;3(4):207-217. doi:10.1111/j.1467-9280.1992.tb00029.x
86. Robertson RJ, Goss FL, Rutkowski J, et al. Concurrent validation of the OMNI Perceived Exertion Scale for resistance exercise. *Med Sci Sports Exerc*. 2003;35(2):333-341. doi:10.1249/01.mss.0000048831.15016.2a
87. Alsubaie SF, Whitney SL, Furman JM, et al. Reliability and validity of ratings of perceived difficulty during performance of static standing balance exercises. *Phys Ther*. 2019;99:1381-1393. doi:10.1093/ptj/pzz091
88. Mansfield A, Thompson S, Puentes Sanchez DLF, Mochizuki G. Validity of measures of reactive balance training intensity. *bioRxiv*. Published online July 26, 2026. doi:10.1101/2025.08.06.668970
89. Espy D. Rate of perceived stability. 2015. <http://csumotionanalysislab.blogspot.com/p/rate-of-perceived-stability.html>
90. Farlie MK, Keating JL, Molloy E, et al. The Balance Intensity Scales for therapists and exercises measure balance exercise intensity in older adults: initial validity using Rasch analysis. *Phys Ther*. 2019;99(10):1394-1404. doi:10.1093/ptj/pzz092