Motion-Rich Interventions in Human Research: Evidence, Boundaries, and the Unmeasured Physical Stimulus

Scientific White Paper SeaKing Solace Science Review 05

Document Status

This scientific white paper was prepared by SeaKing Solace as an evidence-based review of the published scientific literature. It has not been peer reviewed or published by an academic journal. Its purpose is to establish the scientific and evidentiary framework used to inform the SeaKing Solace research program. The underlying studies cited throughout the paper include peer-reviewed publications; their inclusion should not be interpreted as independent validation of SeaKing Solace's hypotheses or proposed applications.

1. Purpose, Scope, and Position in the Scientific Series

1.1 Review Purpose and Central Question

Human exposure to motion occurs across therapeutic, rehabilitative, recreational, and experimental settings. These settings differ substantially in the physical characteristics of the motion delivered, the degree of voluntary participation required, the sensory and social context surrounding the exposure, the clinical populations studied, and the outcomes assessed.

The resulting literature is heterogeneous in a way that is scientifically informative rather than merely inconvenient. Therapeutic horseback riding has produced measurable behavioral and social outcomes in a randomized controlled trial involving children and adolescents with autism spectrum disorder (ASD), demonstrating that a complex intervention containing sustained rhythmic movement can be associated with clinically measurable change in a primary population of interest to this review [1]. Controlled laboratory work provides a different form of evidence: whole-night continuous rocking altered selected sleep-related neural oscillations and next-morning declarative memory performance under a defined experimental protocol, establishing that externally imposed physical motion can itself function as a biologically consequential experimental variable [2]. A double-blind randomized study of whole-body vibration after stroke found no specific benefit of the tested higher-amplitude condition relative to a low-amplitude placebo vibration control, demonstrating that the presence or magnitude of a motion stimulus does not imply benefit and that physical parameters must be evaluated empirically [3].

The clinical evidence is also markedly asymmetric across populations. In postural orthostatic tachycardia syndrome (POTS), a systematic review of randomized treatment trials identified pharmacologic and nonpharmacologic approaches including exercise, sodium, compression, and device-based strategies, but did not identify an established motion-rich therapeutic class comparable to the interventions examined elsewhere in this review [4]. This absence should not be interpreted as evidence that motion-rich interventions are ineffective in POTS. It identifies an unresolved translational question for which direct controlled evidence is presently insufficient.

At the evidence-synthesis level, systematic review and meta-analysis of equine-assisted activities and therapies in ASD confirms measurable effects in selected outcome domains while documenting substantial heterogeneity across intervention formats and measured outcomes [5]. Systematic review of vestibular rehabilitation across neurologic populations similarly indicates that repeated head and body movement occurs within clinically effective rehabilitation programs, although intervention packages typically combine movement with gaze stabilization, balance practice, sensory exposure, and task-specific training [6]. Meta-analytic evidence from whole-body vibration after stroke further illustrates the importance of outcome selection: selected impairment-level outcomes may improve even when gait, activities of daily living, or quality of life do not [7].

Taken together, these literatures establish neither a universal therapeutic effect of motion nor a common mechanism linking all motion-rich interventions. They reveal a more scientifically useful pattern. Human interventions containing substantial motion exposure can produce measurable effects; experimentally imposed motion can itself alter selected human outcomes; null and mixed responses occur under other protocols; and the physical stimulus is often incompletely characterized in clinical studies.

The central question of this review is therefore not whether motion works. The more precise question is what forms of motion-rich intervention have already been studied in humans, what outcomes have been observed, how strong and durable those effects are, how completely the physical motion stimulus has been characterized, and what can legitimately be inferred from this evidence for subsequent translational research.

1.2 Position of Review 05 Within the SeaKing Scientific Series

Review 05 occupies a distinct position within the SeaKing Solace scientific review series. The preceding reviews address progressively related elements of the proposed scientific chain, including motion and vestibular stimulation, vestibular-autonomic interactions, autonomic and vagal regulation, and vestibular stimulation in relation to neuroplasticity. The present review does not repeat those mechanistic arguments. It asks instead whether motion-rich interventions already exist in human research and clinical practice, what measurable outcomes have been associated with them, and how closely existing studies approach isolation of the physical motion stimulus. The positioning of Review 05 within the series is an internal framework statement rather than an empirical claim; no source cited here establishes the sequence of the SeaKing reviews.

The distinction matters because evidence that a biological pathway can respond to vestibular or motion-related input is not equivalent to evidence that a specific motion-rich intervention is clinically effective. Equally, evidence that an intervention such as therapeutic horseback riding [1], controlled rocking [2], or vestibular rehabilitation [6] produces measurable outcomes does not by itself establish which component of that intervention caused the effect. Review 05 therefore occupies the translational space between mechanistic plausibility and intervention-specific experimental testing.

The review also serves a different function from the work that follows it in the broader research program. Questions concerning how natural multidimensional motion should be measured, reproduced, engineered, or delivered on a controlled platform fall outside the primary scope of this paper. Similarly, this review is not designed to establish the efficacy of SeaKing Solace. No study examined here tests the complete SeaKing intervention, its natural vessel-motion exposure, its planned participant populations, or its proposed measurement architecture. The POTS treatment literature, for example, contains randomized evidence for several intervention classes without containing an identified controlled motion-rich treatment [4].

The appropriate role of Review 05 is narrower but scientifically important. It evaluates whether the human literature provides sufficient precedent to regard motion as a serious experimental and translational variable, whether measurable effects survive when complex natural interventions are progressively reduced to more controlled motion exposures, and where the existing literature leaves questions that require direct prospective study.

1.3 Primary and Secondary Populations

Two populations have primary translational importance in this review: ASD and POTS. Their evidence bases are not equivalent and should not be presented as though they were.

ASD has a substantive human intervention literature involving therapeutic horseback riding, broader equine-assisted interventions, mechanical horse simulators, and smaller studies involving vestibular or swing-based exposure. This literature includes randomized controlled trials [1], systematic reviews, null findings, follow-up studies, and mechanical analogues. It therefore permits direct evaluation of intervention effects while also allowing examination of a central causal limitation: whether the motion contained within these interventions can be distinguished from animal interaction, active postural control, therapist contact, novelty, task participation, expectancy, and the surrounding sensory environment.

POTS presents the opposite translational problem. The disorder has an established randomized treatment literature, but direct controlled evidence evaluating motion-rich environmental exposure as a therapeutic intervention was not identified in the evidence examined for this review [4]. POTS therefore functions not as a weaker version of the ASD evidence base but as a distinct evidence gap. The correct scientific conclusion is that the relevant clinical question remains insufficiently tested.

Several secondary populations are included because they provide information that is difficult to obtain from the primary populations alone. In children with cerebral palsy, a stratified single-blind randomized controlled trial comparing an active hippotherapy simulator with a nonmoving simulator condition provides unusually direct evidence concerning the contribution of imposed simulator motion to a selected sitting-balance outcome [8]. Such evidence is highly informative for causal interpretation even though cerebral palsy is not a primary clinical target of this review.

Multiple sclerosis provides another translational model. A randomized controlled trial of vestibular rehabilitation reported improvements in selected fatigue and upright postural control outcomes relative to comparison conditions, demonstrating that movement-based rehabilitation can produce measurable clinical change in a neurologic population [9]. Traumatic brain injury provides complementary evidence concerning durability: vestibular rehabilitation produced an initial between-group advantage in dizziness and mobility outcomes, but those differences were no longer significant at later follow-up, illustrating that an early treatment response cannot be assumed to represent a persistent effect [10].

Stroke, chronic vestibular disorders, older adults at risk of falls, and other neurologic or rehabilitation populations are considered for similar reasons. They permit examination of motion-specific causal manipulation, reactive adaptation, dose, retention, tolerability, and transfer to real-world function. These populations are not included to imply that efficacy in one diagnosis predicts efficacy in ASD or POTS. Their value is translational and methodological: they demonstrate what types of human motion-rich effects can be measured, and what experimental designs are capable of distinguishing a proximal response from adaptation, persistence, or meaningful functional change.

1.4 Review Boundaries

Several boundaries govern the interpretation of evidence throughout this review.

First, an intervention effect is not equivalent to a motion-specific effect. Therapeutic horseback riding includes rhythmic multidimensional movement, but it also includes active postural correction, animal interaction, therapist or instructor contact, proprioceptive input, visual flow, attention, motor planning, motivation, novelty, and social engagement [1]. Sailing, surfing, vestibular rehabilitation, and other motion-rich interventions contain similarly complex combinations of physical and contextual inputs. A favorable outcome from the complete intervention establishes an effect of the intervention as studied, not automatically an effect of motion in isolation.

Second, motion is not treated as a unitary exposure. Rocking, vibration, equine movement, perturbation, self-generated head movement, mechanical simulation, sailing, and surfing differ in axis, frequency, amplitude, acceleration, predictability, temporal variability, posture, active balance demand, sensory context, and participant control. Controlled rocking delivered under a quantitatively specified protocol [2] is a different exposure from a complex naturalistic intervention, and evidence from one category cannot be transferred automatically to another simply because both involve movement.

Third, measurable response is distinguished from therapeutic benefit. An immediate physiological, postural, behavioral, or perceptual response may establish that a stimulus is biologically detectable without demonstrating that the response persists after exposure, transfers to another task or environment, improves participation, or produces meaningful clinical benefit. These stages are treated separately throughout the review.

Fourth, the absence of direct evidence is not treated as evidence of absence. This distinction is particularly important for POTS, where the lack of an identified controlled motion-rich treatment literature defines an experimental gap [4]. It neither establishes efficacy nor refutes the possibility of an effect.

Finally, Review 05 does not establish SeaKing Solace efficacy. The separation between this review and the subsequent engineering and protocol work in the series is an internal scientific-governance boundary; no source examined here establishes SeaKing engineering feasibility or clinical efficacy. The strongest permissible translational inference is that the existing human literature provides sufficient evidence of measurable motion-rich intervention effects, controlled motion-specific responses, parameter-dependent outcomes, and unresolved physical-stimulus characterization to justify direct experimental study of natural multidimensional motion.

Accordingly, the scientific objective of this review is not to infer the answer to those experiments in advance. It is to determine whether the existing human evidence makes those experiments scientifically warranted, and to define, as precisely as the current literature permits, the questions those experiments must resolve.

2. Analytic Framework: Intervention Wrapper, Physical Stimulus, and Causal Inference

2.1 From Intervention Label to Physical Stimulus

A central challenge in evaluating motion-rich interventions is that the name of an intervention rarely specifies the physical stimulus received by the participant. Terms such as therapeutic horseback riding, sailing rehabilitation, surf therapy, vestibular rehabilitation, rocking, and whole-body vibration identify recognizable intervention categories without defining the motion exposure itself.

The gap between label and stimulus is visible across the naturalistic literature. A randomized controlled trial of therapeutic horseback riding in ASD specified session structure, duration, and instructor involvement, and reported measurable behavioral outcomes, but the physical movement delivered to each participant was not quantified as an exposure variable [1]. A mindfulness-based therapeutic sailing program for veterans with psychiatric and substance use disorders combined vessel motion with mindfulness instruction, group participation, skill acquisition, and outdoor environmental exposure [11]. A comparative study of surf therapy for children with disabilities similarly delivered wave and board motion inside a package containing exercise, water immersion, instruction, and social engagement [12]. A feasibility and safety study of sailing-based rehabilitation for rare skeletal disorders used wearable sensors and patient-reported outcomes, moving closer to instrumented characterization while still evaluating a multimodal program rather than an isolated motion exposure [13].

A minority of studies take the opposite approach and define the physical stimulus explicitly. Controlled rocking protocols specify bed displacement, frequency, and duration as experimental parameters [2, 14]. Biomechanical studies quantify three-dimensional pelvis motion during walking and during therapeutic horse riding [15], and characterize the specificity and variability of trunk kinematics on a mechanical horse across frequency, direction, and support conditions [16]. Whole-body vibration trials define frequency and amplitude precisely enough to construct a placebo-amplitude control condition [3].

This contrast should not be read as evidence that the physical motion component is inactive within naturalistic packages, nor that quantified studies have established one universal motion dose. It establishes a narrower and more useful methodological point: the physical stimulus is measurable, and whether it has been measured varies substantially across the literature.

2.2 Externally Imposed, Self-Generated, and Hybrid Motion

Motion-rich interventions differ in who generates the movement, and this distinction has direct consequences for causal interpretation.

Externally imposed motion is delivered to a largely passive participant. Whole-night rocking during sleep is the clearest example, since the participant is not awake, not balancing, and not performing a task while the motion is applied [2]. Self-generated motion is produced by the participant's own movement. Vestibular rehabilitation exercises requiring repeated head movement during gaze-stabilization training place the participant in active control of the stimulus [17]. Hybrid motion occupies the space between these categories: an externally imposed disturbance is delivered, but the participant must generate an active response to it. Perturbation-based balance training after stroke is a direct example, since the imposed perturbation is followed by a required reactive stepping or postural recovery response [18].

Therapeutic horseback riding sits within the hybrid category as well. The horse generates the movement, but the rider must continuously respond to it through active postural correction while also participating in instructed tasks [1]. Mechanical horse studies show that trunk response varies with support condition, which further indicates that the participant's postural role modifies the effective stimulus even when the delivered motion is fixed [16].

These categories should not be treated as therapeutically equivalent. They differ in the sensory consequences of the movement, in the presence or absence of active motor planning, and in the cognitive and attentional demands imposed; self-generated movement is also classically thought to be accompanied by an efference copy signal not present during purely externally imposed motion, though this distinction was not directly tested by the sources reviewed here. A finding obtained under one class does not transfer automatically to another.

2.3 Physical Motion Characteristics as Dose

Where motion has been characterized, the literature demonstrates that physical variables can be measured and that they differ substantially across protocols.

Controlled rocking studies specify displacement and frequency and hold them constant across a defined exposure window [2, 14]. Biomechanical work quantifies pelvis motion in three dimensions during therapeutic horse riding and compares it directly against walking [15]. Mechanical horse studies show that trunk kinematics depend on the frequency and direction of the delivered motion and on the support condition of the rider [16]. Direct instrumented observation of physical therapy incorporating equine movement has measured the coupling between horse and child movement during treatment sessions [19]. Whole-body vibration trials specify frequency and amplitude with sufficient precision to distinguish an active condition from a low-amplitude placebo condition [3], and meta-analytic work across whole-body vibration protocols reports variation in frequency, duration, and session structure across trials [7].

These variables constitute a candidate dose vocabulary for motion-rich research: axis composition, frequency, amplitude, acceleration, kinematic pattern, support condition, session duration, and cumulative exposure. Their measurability is established. What has not been established is an optimal setting for any of them. The protocols above were designed to answer different questions in different populations, and no optimal parameter set for natural multidimensional motion can be derived from them.

2.4 Intervention Effect Versus Motion-Specific Effect

Four levels of causal resolution appear in the motion-rich literature, and distinguishing them is essential to interpreting the evidence.

At the lowest resolution is whole-package efficacy. A randomized trial of therapeutic horseback riding demonstrated behavioral improvement relative to a control condition, establishing an effect of the intervention as delivered without isolating any component [1].

Active-comparator designs increase resolution by testing whether the specific package outperforms a different structured activity. A comparative effectiveness study of therapeutic riding and mindfulness in adolescents with autism found that both recreational therapy interventions produced improvement, a pattern that constrains claims of specificity for the equine component [20].

Component manipulation increases resolution further. A stratified single-blind randomized trial in cerebral palsy compared an active hippotherapy simulator against a nonmoving simulator condition, holding the seat, posture, and environment approximately constant while varying only whether the device moved [8]. This design tests the contribution of imposed motion directly rather than inferring it.

Physical-stimulus manipulation provides the highest causal resolution among the reviewed designs. A double-blind randomized trial of whole-body vibration compared 25 Hz at 3.75 mm against 25 Hz at 0.2 mm, varying amplitude while preserving the appearance and procedure of the intervention [3]. The tested higher-amplitude condition was not superior.

Package-level benefit cannot be converted into motion-specific causality. The distinction between these four levels is used throughout this review to characterize what each body of evidence can support.

2.5 Response, Retention, Transfer, and Functional Benefit

Motion-rich outcomes are reported at several temporal and functional levels, and the literature demonstrates empirically that these levels can diverge.

Immediate or within-intervention response establishes that a stimulus is biologically or behaviorally detectable. Retention asks whether an observed change persists after the intervention period ends. A long-term follow-up of therapeutic horseback riding in youth with ASD examined whether initial trial effects were maintained after the intervention concluded [21], and the simulator trial in cerebral palsy assessed a selected sitting-balance outcome following a defined course of imposed motion [8]. Transfer asks whether improvement extends beyond the trained condition into a different task, environment, or functional domain. A randomized trial of perturbation-based balance training in chronic stroke examined whether trained reactive-balance improvement translated into reduced falls in daily life [22].

These levels can dissociate. In multiple sclerosis, a randomized controlled trial comparing customized with booklet-based vestibular rehabilitation reported selected secondary advantages without demonstrating superiority on the primary dizziness handicap outcome [23]. After traumatic brain injury, an initial between-group advantage in dizziness and mobility outcomes was no longer significant at later follow-up [10]. In whole-body vibration after stroke, meta-analysis reported selected impairment-level improvements alongside null pooled effects for gait, activities of daily living, and quality of life [7].

A proximal response, an impairment-level score, or a trained-task gain therefore cannot be equated with durable functional efficacy. Each represents a distinct evidentiary claim requiring its own demonstration.

3. Equine Interventions in Autism Spectrum Disorder

3.1 Equine Intervention Terminology and Intervention Structure

The equine intervention literature uses overlapping terminology for interventions that differ materially in structure, personnel, and therapeutic intent. A systematic mapping review of autism and equine-assisted interventions documents this heterogeneity directly, identifying substantial variation in intervention format, session structure, provider discipline, and outcome selection across the published evidence [24].

Broad categories can be distinguished in principle. Hippotherapy denotes the use of equine movement by a licensed therapist as a treatment strategy within a therapy plan. Therapeutic riding denotes instruction in riding skills adapted for individuals with disabilities. Equine-assisted services and equine-assisted activities describe a wider range of structured human-horse interactions including groundwork, care activities, and unmounted engagement. Systematic review and meta-analysis of equine-assisted activities and therapies in ASD confirms measurable effects in selected outcome domains while documenting the heterogeneity across these formats [5], and meta-analytic evidence for therapeutic horseback-riding programs specifically reports effects on social and communication outcomes in children with ASD [25].

These categories should not be pooled as though they were a single intervention. They differ in the amount of time spent mounted, the amount of movement received, the degree of active postural demand, the extent of animal handling and care, the therapist or instructor role, and the structure of the surrounding session. Where this review refers to equine interventions collectively, that usage denotes a family of related interventions and not a uniform treatment.

3.2 Controlled ASD Evidence

The strongest direct evidence in this domain comes from randomized controlled trials in ASD populations.

A randomized controlled trial of therapeutic horseback riding in children and adolescents with ASD reported improvement in irritability and other measured behavioral outcomes relative to a control condition over the trial period [1]. A separate randomized controlled study of a standardized equine-assisted therapy program in children with ASD reported improvement in selected social functioning and executive-related outcomes [26]. An earlier controlled study of therapeutic horseback riding reported improvement in selected social functioning measures relative to a waitlist condition [27].

These positive findings are specific rather than general. Each trial measured a defined outcome set in a defined population under a defined protocol, and improvement in one outcome domain does not establish improvement across the full range of ASD-relevant outcomes.

The controlled literature also contains directly limiting evidence. A replication pilot trial of therapeutic horseback riding that included cortisol collection in children on the autism spectrum did not reproduce the full pattern of the original findings, and the physiological measure did not behave as a specific marker of intervention response [28]. An experimental analysis of the effects of therapeutic horseback riding on the behavior of children with autism reported null results for the targeted behavioral outcomes under the tested design [29].

Synthesis-level evidence reflects this mixture. Meta-analysis of equine-assisted services and social skills in ASD reports measurable pooled effects alongside heterogeneity across included studies [30], and meta-analytic evidence for therapeutic riding programs likewise reports domain-specific rather than uniform effects [25]. Equine interventions in ASD should therefore be described as producing measurable improvement in selected outcomes under selected protocols, not as broadly or uniformly effective.

3.3 Replication, Null Findings, and Outcome Heterogeneity

Three distinct forms of limitation appear within the ASD equine literature, and they constrain interpretation in different ways.

The first is incomplete replication. The replication pilot trial of therapeutic horseback riding with cortisol collection did not reproduce the original effect pattern in full [28]. This is not equivalent to refutation, but it does prevent the original result [1] from being treated as an established and reliably reproducible effect.

The second is acute physiological nonspecificity. The same replication work indicates that a candidate physiological marker did not track intervention response in the expected manner [28], and the comparative effectiveness study of therapeutic riding against mindfulness found that a structurally different recreational therapy intervention produced comparable improvement on measured outcomes [20]. An outcome that improves under both an equine and a nonequine structured activity cannot be attributed specifically to the equine component.

The third is direct behavioral null evidence. The experimental analysis of therapeutic horseback riding reported null findings for the targeted behaviors under its tested design [29].

Heterogeneity in outcome domain compounds these limitations. Randomized and controlled trials in this literature report improvement in some measured domains and not others [1, 26], and systematic review and meta-analysis documents variability in which domains show effects across studies [5].

This pattern should not be converted into a claim that equine interventions are ineffective overall. The accurate characterization is that the evidence base contains genuine positive controlled findings, partial replication, at least one direct behavioral null result, and substantial variation in which outcomes respond.

3.4 Retention and Generalization

Durability and generalization have been examined less often than initial effect.

A long-term follow-up of the randomized therapeutic horseback riding trial in youth with ASD examined maintenance of effects after the intervention period concluded and reported persistence of selected outcomes [21]. A multiple case design examining therapeutic horseback riding outcomes for parent-identified goals in children with ASD assessed dosing and generalization to home and community settings, providing direct information about whether trained gains appear outside the intervention environment [31].

Both sources address durability and generalization directly rather than by inference, which distinguishes them within this literature. Their design characteristics nevertheless constrain the strength of the resulting claim: follow-up periods are finite, outcome sets are specific, and the case-design evidence involves a small number of participants under individualized goal structures.

Selected equine-related effects can therefore persist or generalize under the conditions studied. Equine benefits should not be characterized as reliably durable or broadly generalized across outcomes, settings, and participants.

3.5 What the Live-Horse Literature Does Not Isolate

The live-horse evidence base is a package-level literature. Even where controlled trials demonstrate improvement [1, 26], the intervention delivered includes the movement of the animal together with animal interaction, instructor and therapist contact, active postural demand, task instruction, novelty, outdoor environment, and social engagement. No trial in this group manipulates the movement component while holding the remainder of the package constant.

Two further findings sharpen this limitation. The comparative effectiveness study showing that a nonequine recreational therapy produced comparable improvement indicates that the measured outcomes are not unique to equine exposure [20], and the experimental behavioral analysis reporting null findings indicates that the package does not reliably produce change in every targeted behavior [29]. The partial replication result adds a further constraint on attributing effects to any single component [28].

Biomechanical studies characterize the motion itself without resolving its clinical contribution. Three-dimensional quantification of pelvis motion during therapeutic horse riding establishes what movement is delivered and how it compares with walking [15], and instrumented observation of physical therapy incorporating equine movement measures horse-child movement coupling during treatment [19]. These studies describe the physical stimulus precisely. They do not test whether that stimulus causes the clinical outcomes reported in the trial literature.

The live-horse literature therefore establishes that a multimodal intervention containing substantial rhythmic movement can produce measurable outcomes in ASD, and separately establishes that the movement within that intervention can be quantified. It does not establish that horse motion, or vestibular stimulation arising from it, is the active ingredient.

4. Mechanical Equine Simulators and Controlled Equine-Motion Analogues

4.1 Why Mechanical Equine Analogues Matter

The principal limitation of the therapeutic horseback riding literature is not the quality of its strongest clinical trials but the complexity of the intervention itself. Mounted equine interventions combine horse-generated movement, continuous postural adaptation, therapist interaction, instructor guidance, social engagement, environmental novelty, and direct interaction with a live animal. Even well-designed randomized trials therefore establish the effectiveness of the intervention package without identifying which components are necessary or sufficient to produce the observed outcomes.

Mechanical equine simulators approach this problem differently. Rather than asking whether horseback riding is clinically beneficial, they ask what happens when aspects of horse-like movement are mechanically reproduced while the live animal is removed. A stratified single-blind randomized controlled trial in children with cerebral palsy used an active simulator that could be operated in moving and nonmoving conditions while holding the surrounding intervention structure constant [8]. Biomechanical work has quantified pelvis motion during therapeutic horse riding [15] and the specificity and variability of trunk kinematics on a mechanical horse across frequency, direction, and support conditions [16].

Removing the animal does not create a purely passive-motion condition. Participants on a mechanical simulator continue to perform active postural correction, and simulator trunk response depends on the support condition provided to the rider [16]. Mechanical simulation should therefore be understood as narrowing, not eliminating, the complexity of the live-horse intervention, and it should not be assumed to be biomechanically equivalent to riding a horse; a direct comparison of live-horse and mechanical-simulator groups is examined in Section 4.4 [32], and a systematic review and meta-analysis of mechanical horse-riding simulator interventions in cerebral palsy is examined in Section 4.7 [33]. That the two exposures may differ in their biomechanical detail is itself a proposition requiring empirical validation, not an assumption this review makes in advance.

4.2 Simulated Developmental Horse-Riding in ASD

A controlled study evaluated a simulated developmental horse-riding program in children with autism and reported improvement in motor proficiency and sensory-integrative function following the program, with the authors reporting that gains were maintained at follow-up [34]. This is the only source in the canonical evidence base that evaluates a mechanical equine analogue directly in an ASD population, which gives it particular translational relevance to this review.

The design of this study constrains the strength of the resulting claim. It was not described as randomized, and the reported persistence of effects should be read as the authors' own follow-up observation rather than as evidence from a controlled retention design. The outcomes measured concerned motor proficiency and sensory integration rather than the core social-communication or behavioral domains emphasized in the live-horse ASD literature. The improvement observed should not be attributed solely to vestibular motion, since a simulated riding program of this kind also involves postural demand, session structure, and instructor interaction.

4.3 Simulator Motion ON Versus OFF

The cerebral palsy simulator trial provides the clearest movement-specific comparison in the equine literature because its principal experimental manipulation was whether the simulator moved [8]. Participants assigned to the active-motion condition demonstrated greater improvement in a sitting-balance outcome than those assigned to the nonmoving simulator condition, while the seat, posture, and surrounding treatment structure were held approximately constant.

This design substantially strengthens causal inference relative to comparisons between live horseback riding and an unrelated control condition, where the intervention and control differ along many dimensions simultaneously. The ON-versus-OFF comparison isolates one dimension. The resulting claim is nonetheless bounded to what was tested: a single sitting-balance outcome, in children with cerebral palsy, using one simulator waveform. It should not be generalized to other outcomes, other diagnoses, other simulator motion patterns, or to natural multidimensional motion of the kind under consideration elsewhere in the SeaKing research program.

4.4 Live Horse Versus Mechanical Simulator

A direct comparison examined the effects of hippotherapy and a horse-riding simulator on balance in children with cerebral palsy and reported improvement in balance outcomes in both the live-horse and the mechanical-simulator groups [32]. Biomechanical characterization of horse and simulator motion provides context for interpreting this comparison: pelvis motion during therapeutic horse riding has been quantified in three dimensions [15], and trunk kinematics on a mechanical horse vary with frequency, direction, and support condition [16], indicating that the two exposures share general movement characteristics without having been shown to be identical.

A small trial in which both groups improved does not establish that either exposure was biomechanically identical to the other. The study also did not include an inactive or nonmoving control, so it cannot by itself establish that either intervention was superior to no treatment. Its contribution is narrower: within the population and outcome tested, a mechanically generated approximation of horse movement produced a comparable pattern of improvement to movement generated by a live animal.

4.5 Biomechanics of Horse and Simulator Motion

Three strands of biomechanical evidence characterize the physical stimulus underlying equine and simulator interventions. Three-dimensional analysis of human pelvis motion during walking and during therapeutic horse riding shows that riding produces coordinated, multiplanar pelvic displacement distinct from gait [15]. Mechanical horse studies demonstrate that trunk kinematics are specific to the frequency, direction, and support condition of the delivered motion, and that this specificity varies across riders [16]. Direct instrumented observation of physical therapy incorporating equine movement has measured the coupling between horse and child movement during treatment sessions in children with cerebral palsy, providing an objective record of the physical interaction rather than a procedural description of the session [19].

Together these studies establish that horse-generated and simulator-generated motion are multidimensional, that they can be quantified rather than only described, and that the response of the rider or participant depends on measurable physical parameters. Kinematic characterization of this kind does not by itself establish clinical efficacy. Quantifying pelvic displacement, trunk oscillation, or horse-child movement coupling identifies the physical stimulus; it does not identify which, if any, physiological pathway produces a therapeutic effect.

4.6 MiraColt and Emerging Controlled-Motion Programs

Devices designed to reproduce aspects of equine movement under controlled mechanical conditions, including platforms such as MiraColt, are conceptually relevant to this review because they extend the same logic examined throughout this section: preserving horse-like motion while increasing experimental control. The peer-reviewed mechanical-horse biomechanics literature cited above, including the characterization of trunk kinematics on a mechanical horse [16], establishes that this general class of device can deliver quantifiable, frequency- and direction-specific motion.

No canonical source in the evidence base examined for this review reports peer-reviewed clinical efficacy data for MiraColt specifically. Public description of the device, its intended applications, and ongoing development activity does not constitute peer-reviewed efficacy evidence, and this review does not treat such material as a clinical evidence source. MiraColt is therefore discussed here only as an example of continued development interest in mechanically reproducing equine motion under controlled conditions. Its clinical status is an evidence gap, not an evidence-supported therapy, and the appropriate conclusion is that peer-reviewed controlled clinical studies of this specific platform were not identified in the evidence base examined for this review.

4.7 Mechanical Equine Synthesis

The mechanical equine literature strengthens the scientific interpretation of equine-based motion interventions without resolving every causal question. Controlled comparison of moving and nonmoving simulator conditions supports a movement-specific contribution to a defined postural outcome [8]. A direct comparison of live-horse and mechanical-simulator groups shows that both can be associated with improved balance outcomes [32], and a systematic review and meta-analysis of mechanical horse-riding simulator interventions in cerebral palsy summarizes this broader pattern across studies [33]. In ASD specifically, a simulated developmental horse-riding program was associated with improved motor proficiency and sensory-integrative function [34]. Biomechanical work establishes that horse-generated and simulator-generated motion are multidimensional and can be quantified [15, 16].

Several boundaries remain. The evidence does not establish that mechanical simulators are biomechanically equivalent to live horseback riding. It does not demonstrate that simulator-derived benefits predict the behavioral or social-communication outcomes reported in the live-horse ASD literature. It does not establish a single effect size that generalizes across diagnoses, and durability beyond the periods studied remains largely unexamined. Mechanical equine simulation should be understood as an experimental bridge that improves causal resolution relative to natural riding, not as a demonstrated substitute for it.

5. Swing-Based Vestibular Interventions in Autism Spectrum Disorder

5.1 Swing-Based Vestibular Interventions in ASD

The direct ASD swing evidence base in this review is small and consists of two studies addressing different questions. A feasibility study used posturography to examine the immediate effects of vestibular swing therapy in children with autism spectrum disorders, establishing that objective postural measurement is achievable in this population following acute vestibular exposure [35]. A randomized study examined the effect of a platform swing on the independent work behaviors of children with autism spectrum disorders under a controlled acute exposure [36]. Together these represent the entire direct swing-specific evidence available for this review; they should not be supplemented with inference from the broader clinical use of swinging in sensory integration practice, which lies outside the audited evidence base.

5.2 Objective Acute Postural Response

The posturography feasibility study demonstrated that acute postural response to vestibular swing exposure in children with ASD can be measured objectively using instrumented assessment [35]. This establishes methodological feasibility: postural response to an acute vestibular swing exposure is a measurable outcome in this population, and it can be captured with greater precision than behavioral observation alone. A feasibility study of this kind is not designed to and does not demonstrate clinical benefit. Its contribution is to establish that objective outcome measurement is possible in future controlled work, not to support a therapeutic claim.

5.3 Randomized Acute Behavioral Null Evidence

The randomized platform-swing study tested a defined five-minute swing exposure against a comparison condition and found no significant improvement in the specified independent-work behaviors [36]. This is a direct null finding under a randomized design, and it should be reported as such rather than reframed as inconclusive.

The null result is specific to the tested protocol. It applies to a single acute five-minute exposure, to the independent-work behavioral outcomes specified in that study, and to the population and setting examined. It should not be generalized to repeated-session swing exposure, to other swing parameters such as different amplitudes or durations, or to other behavioral or physiological outcomes that were not measured.

5.4 Repeated-Dose Efficacy Remains Unresolved

Between them, the feasibility study and the randomized acute trial establish that vestibular swing exposure was followed by a measurable postural response and that a single brief exposure was not followed by a measurable behavioral benefit in the outcome tested [35, 36]. Neither study, individually or together, evaluated repeated-session swing exposure delivered over a course of treatment. The canonical evidence base therefore does not establish repeated-dose clinical efficacy of swing therapy in ASD.

This conclusion should be read as an evidence gap rather than as evidence of ineffectiveness. The published direct evidence is limited to acute exposure. Whether repeated, dosed vestibular swing exposure produces cumulative behavioral or functional benefit in ASD has not been tested within the sources examined for this review and remains an open question for future controlled research.

6. Controlled Rocking and Passive Rhythmic Motion

6.1 Controlled Rocking as a Motion-Specific Experimental Model

Controlled rocking studies provide one of the most direct motion-versus-stationary experimental models available in this review. Two sleep-laboratory studies deliver a quantitatively specified rocking exposure and compare it against a stationary or reduced-motion condition within the same participants. A study of whole-night continuous rocking entrained spontaneous neural oscillations and produced measurable benefits for sleep and next-morning memory under a defined lateral rocking protocol [2]. A separate study examined the effect of a slowly rocking bed on sleep using a different rocking protocol and outcome pattern [14].

These two protocols should not be treated as interchangeable versions of one rocking exposure. They differ in rocking axis, timing, and duration, and their outcomes differ accordingly. Their value to this review is methodological as much as substantive: both specify the physical motion delivered as a controlled experimental parameter, in contrast to the majority of the naturalistic literature discussed elsewhere in this review. Findings from these sleep-laboratory protocols should not be generalized to clinical rehabilitation populations or to other forms of motion without direct testing.

6.2 Rocking-Associated Sleep and Memory Effects

The continuous whole-night rocking study reported that lateral rocking during sleep was associated with entrainment of spontaneous neural oscillations, along with selected improvements in sleep architecture and next-morning declarative memory performance relative to the stationary control condition [2]. This is a controlled within-subject demonstration that a specific, quantitatively defined passive motion exposure can alter both a neurophysiological measure and a cognitive outcome.

The result is specific to the tested protocol. It should not be read as establishing that rocking generally improves sleep or memory, since the rocking axis, frequency, and duration were fixed within this single study design and have not been shown to generalize to other rocking parameters, populations, or exposure durations.

6.3 Mixed and Null Rocking Findings

The slowly rocking bed study reported a substantially different outcome pattern. Whole-night sleep and memory measures were largely null under this alternative protocol, with transient changes in N2 sleep and spindle activity observed only during the stimulation period itself rather than as a durable overnight effect [14].

This null and mixed result is scientifically important in its own right. It demonstrates that not every controlled rocking protocol reproduces the same sleep and memory benefits, and it should not be interpreted as evidence that passive rocking has no effect on sleep-related physiology. The correct reading is narrower: this particular protocol did not reproduce a durable whole-night benefit, while producing a detectable transient physiological change during active stimulation.

6.4 Parameter, Timing, and State Dependence

Read together, the two controlled rocking studies demonstrate that differing rocking protocols can produce materially different outcomes despite sharing the general category of passive lateral rocking during sleep [2, 14]. One protocol produced measurable sleep, oscillatory, and memory benefits; a different protocol produced a largely null whole-night result with only a transient physiological change during stimulation.

This pattern is consistent with an inference of parameter, timing, or state dependence: outcome can vary with the specific rocking frequency, axis, duration, and the sleep stage during which motion was delivered. These two studies do not identify which parameters are responsible for the divergence, and they do not establish an optimal rocking axis, frequency, or amplitude. Their combined contribution is to demonstrate, under tightly controlled conditions, that the outcome of a passive motion exposure depends on how that exposure is delivered rather than on the mere presence of motion.

7. Movement-Rich Vestibular Rehabilitation

7.1 Repeated Head and Body Motion in Vestibular Rehabilitation

Vestibular rehabilitation is a real, widely used human clinical intervention class built around repeated head and body movement, applied across peripheral vestibular and neurologic populations. A randomized controlled trial evaluated booklet-based self-management of symptoms in Ménière disease [37]; a study examined recovery of dynamic visual acuity in unilateral vestibular hypofunction following gaze-stabilization exercise [17]; a randomized controlled trial examined vestibular rehabilitation for multiple sclerosis-related fatigue and upright postural control [9]; a comparative study evaluated vestibular rehabilitation against noisy galvanic vestibular stimulation in multiple sclerosis [38]; a randomized controlled trial compared customized with booklet-based vestibular rehabilitation for vestibulopathy in multiple sclerosis [23]; a preliminary randomized controlled trial examined vestibular rehabilitation training in subacute stroke [39]; a randomized controlled trial examined vestibular rehabilitation for dizziness and balance problems after traumatic brain injury [10]; and a systematic review synthesized the efficacy of vestibular rehabilitation across neurologic disorders more broadly [6].

This body of work spans peripheral vestibular disease, multiple sclerosis, stroke, and traumatic brain injury. These programs should not be pooled as a single physical stimulus. They differ in exercise selection, intensity, supervision, and the specific movement patterns prescribed, and diagnosis-specific findings should be read within their own population rather than generalized across the full vestibular rehabilitation literature.

7.2 Peripheral Vestibular Disorders

In peripheral vestibular populations, booklet-based self-management of Ménière disease symptoms was evaluated in a randomized controlled trial, providing a comparator condition that itself contains structured guidance rather than an inert control [37]. Gaze-stabilization exercise produced recovery of dynamic visual acuity in unilateral vestibular hypofunction, directly linking repeated head-movement exercise to a measurable oculomotor outcome [17]. A study of habituation and gaze-stability exercises in unilateral vestibular hypofunction reported improvement under a small preliminary design [40].

These studies support improvement in selected peripheral vestibular outcomes following movement-based rehabilitation. They do not establish that head movement alone is the proven active ingredient. Several of the comparator and active conditions in this literature share structural components such as guided instruction and repeated practice, which complicates attribution of the observed benefit uniquely to the physical motion involved.

7.3 Multiple Sclerosis

Multiple sclerosis provides three relevant sources. A randomized controlled trial found that vestibular rehabilitation improved multiple sclerosis-related fatigue and upright postural control relative to a comparison condition [9]. A comparative study found that vestibular rehabilitation and noisy galvanic vestibular stimulation both improved dizziness and balance outcomes in multiple sclerosis, without establishing a unique advantage for repeated physical movement over the electrical stimulation comparator [38]. A randomized controlled trial and cost-effectiveness analysis comparing customized with booklet-based vestibular rehabilitation for vestibulopathy in multiple sclerosis found that the more customized, intensive rehabilitation program did not outperform the booklet-based comparator on the primary Dizziness Handicap Inventory outcome, although selected secondary outcomes favored the customized approach [23].

Taken together, these three sources support that vestibular rehabilitation can produce selected benefits in multiple sclerosis, that at least short-term retention of some benefit is achievable, and that a more customized or intensive rehabilitation format is not uniformly superior to a simpler comparator. The primary-outcome null result in the customized-versus-booklet trial should be preserved rather than interpreted away, since it directly limits any inference that greater intervention intensity produces proportionally greater benefit [23].

7.4 Stroke and Traumatic Brain Injury

In subacute stroke, a preliminary randomized controlled trial of vestibular rehabilitation training reported selected gait and mobility improvements relative to comparison conditions [39]. In traumatic brain injury, a randomized controlled trial of vestibular rehabilitation reported an initial between-group advantage in dizziness and balance outcomes that was explicitly not retained at later follow-up, with the advantage no longer significant once the study reached its longer-term assessment point [10].

These two sources should be read together rather than separately, because they illustrate the same evidentiary principle from opposite directions. Selected functional gains are achievable after stroke and after traumatic brain injury using movement-rich vestibular rehabilitation, but durable neurologic benefit and motion-specific causality are not established by either study. The traumatic brain injury result in particular demonstrates directly that an early treatment advantage cannot be assumed to persist.

7.5 Repeated Head Movement as a Candidate Shared Component

Two active vestibular exercise approaches, evaluated in different studies, produced improvement despite differing in specific technique: the habituation and gaze-stability exercise study in unilateral vestibular hypofunction [40] and the gaze-stabilization exercise study measuring recovery of dynamic visual acuity [17], with the Ménière self-management trial providing an additional structured comparator context [37]. The pattern across these active approaches is consistent with the hypothesis that repeated head movement common to multiple vestibular exercise techniques contributes to the improvement observed, rather than any single exercise technique being uniquely responsible.

This interpretation should be treated as hypothesis-generating rather than established. The habituation and gaze-stability study is a small preliminary trial, and cross-study comparison of different exercise approaches carried out in different samples cannot substitute for a head-to-head test of the shared-mechanism hypothesis. A small preliminary sample size does not constitute proof that head movement is the unique or primary active ingredient across these approaches.

7.6 Simulator-Based Vestibular Desensitization

A study of simulator-based rehabilitation in refractory dizziness examined whether adding whole-body and visual-motion simulator exposure to customized vestibular rehabilitation produced additional benefit, and reported selected additional improvement in symptom and posturography outcomes when the simulator exposure was included [41]. This provides evidence that a more intensive, motion-inclusive rehabilitation format can add measurable benefit beyond standard customized vestibular rehabilitation in a population with treatment-refractory symptoms.

The simulator exposure in this study bundled whole-body physical motion together with visual-motion and desensitization components. The added benefit observed cannot be attributed specifically to the physical motion component in isolation, since the visual and desensitization elements were delivered concurrently and were not manipulated independently.

7.7 What Vestibular Rehabilitation Can and Cannot Establish About Motion

Across peripheral vestibular disease, multiple sclerosis, stroke, and traumatic brain injury, vestibular rehabilitation programs built around repeated head and body movement produce measurable clinical benefit in selected outcomes [37, 17, 9, 23, 10, 41, 40]. The systematic review of vestibular rehabilitation efficacy across neurologic disorders supports this pattern at the level of the broader literature [6].

Three limits constrain what this literature establishes about motion specifically. Durability is variable: benefit was not retained at later follow-up in traumatic brain injury [10], and a more intensive customized program did not outperform a simpler comparator on the primary outcome in multiple sclerosis [23]. Active comparators frequently perform similarly to the primary intervention, a pattern already established for multiple sclerosis in Section 7.3, which limits claims of motion-specific superiority. And the causal primacy of repeated movement itself remains unresolved, since exercise-based vestibular rehabilitation programs bundle head movement with instruction, practice structure, and, in the case of simulator-based desensitization, visual-motion components that cannot presently be separated from the physical motion delivered [41].

Vestibular rehabilitation therefore establishes package-level clinical efficacy across several populations, with efficacy that varies by outcome and by durability, rather than a proven motion-only mechanism.

8. Perturbation-Based Balance Training: Repeated External Motion and Adaptive Motor Responses

8.1 Perturbation-Based Balance Training as a Motion-Rich Learning Paradigm

Perturbation-based balance training delivers an externally imposed disturbance and requires the participant to generate an active reactive recovery response, most often a compensatory step or postural correction. A randomized controlled trial evaluated perturbation-based balance training in subacute stroke [18]; a randomized controlled trial examined whether perturbation-based balance training prevented falls in chronic stroke [22]; a systematic review and meta-analysis of preliminary randomized controlled trials evaluated fall prevention from perturbation-based balance training [42]; a systematic review examined perturbation-based balance training for reducing fall risk after stroke [43]; and a systematic review examined mechanisms and training parameters underlying reduced falls and fall injuries in older people [44].

This paradigm is a distinct class of motion-rich intervention from the passive rhythmic exposures examined elsewhere in this review. Rocking, sailing, and equine motion are predominantly predictable and rhythmic; perturbation training is unpredictable by design, and the therapeutic target is the participant's reactive motor response to the disturbance rather than passive exposure to the motion itself. Perturbation-based learning should not be treated as equivalent to rocking, riding, or vessel motion on the basis that all involve imposed movement.

8.2 Reactive-Balance Improvement

Across the perturbation training literature, reactive balance and related trained perturbation-response capabilities improve with training. The subacute stroke trial reported improvement in reactive balance measures following a defined perturbation training program [18]. The chronic stroke fall-prevention trial reported improvement in reactive-balance capability as a trained outcome [22]. The systematic review and meta-analysis of preliminary randomized trials [42] and the systematic review of mechanisms and training parameters in older people [44] both support this pattern of trainable reactive-balance improvement across the included studies.

A trained gain in reactive-balance capability under laboratory or clinical testing conditions is not equivalent to a reduction in real-world falls. These are separate outcomes, and the relationship between them is addressed directly in the sections that follow.

8.3 Falls in Older Adults

Meta-analytic evidence in older adults supports a reduction in fall and fall-injury rates associated with perturbation-based balance training. The systematic review and meta-analysis of preliminary randomized controlled trials found evidence consistent with reduced falls following perturbation training [42], and the systematic review addressing mechanisms and training parameters reported that perturbation-based balance training reduced falls and fall injuries in older people across the included evidence [44].

This fall-reduction signal is specific to older-adult populations as studied in these reviews. It should not be generalized to stroke or to other clinical populations without direct evidence, since the balance impairment, fall mechanism, and rehabilitation context differ meaningfully between community-dwelling older adults and neurologic populations such as stroke survivors.

8.4 Stroke: Retention Without Demonstrated Fall Reduction

In chronic stroke, the randomized controlled trial testing whether perturbation-based balance training prevented falls found that trained reactive-balance improvement was retained, but did not find a significant reduction in community falls, the study's primary real-world outcome [22]. A systematic review of perturbation-based balance training for reducing fall risk after stroke situates this result within the broader stroke-specific literature, in which fall-reduction evidence remains limited [43].

This is a direct and important dissociation. Reactive-balance capability, a trained and retained impairment-level outcome, did not translate into the study's primary measure of real-world fall reduction in chronic stroke. A null primary fall outcome of this kind should not be reinterpreted as successful real-world transfer merely because a related secondary or impairment-level measure improved.

8.5 Dose and Perturbation Characteristics

Evidence across the perturbation literature is consistent with a dose-associated signal, in which greater training exposure is associated with a subgroup pattern of improved outcomes. The systematic review addressing mechanisms and training parameters discusses training dose and parameter characteristics in relation to fall outcomes in older adults [44], while the meta-analysis [42] and the chronic-stroke randomized controlled trial [22] provide complementary context on variation in training exposure across the included and directly studied protocols.

This dose-associated pattern should be treated as a subgroup signal rather than an established causal dose-response relationship. It does not establish six hours, or any other specific quantity of training, as a universal minimum effective dose. The perturbation-training literature remains heterogeneous in protocol, population, and outcome, and any apparent threshold observed within a subgroup analysis should not be treated as a prescriptive parameter for future motion-rich intervention design.

9. Whole-Body Vibration and Mechanically Generated Oscillatory Motion

9.1 Whole-Body Vibration as a Parameterized Motion Platform

Whole-body vibration (WBV) is a physically parameterizable, externally imposed motion-platform class with a controlled human evidence base in stroke rehabilitation. A double-blind randomized controlled study examined whole-body vibration training in chronic stroke using a placebo-amplitude design [3]. A randomized controlled trial examined whole-body vibration in the horizontal direction for stroke rehabilitation [45]. A systematic review and meta-analysis synthesized the effects of whole-body vibration training on physical function, activities of daily living, and quality of life in patients with stroke [7].

WBV platforms deliver high-frequency, low-amplitude oscillatory motion that is mechanically and parametrically distinct from the low-frequency, larger-amplitude multidimensional motion under consideration elsewhere in the SeaKing research program. High-frequency vibration of this kind should not be treated as equivalent to low-frequency natural motion; the two occupy different regions of the physical parameter space, and evidence from one should not be assumed to transfer to the other.

9.2 Placebo-Amplitude Null Evidence

The double-blind randomized controlled study of whole-body vibration training in chronic stroke compared a 25 Hz, 3.75 mm active vibration condition against a 25 Hz, 0.2 mm placebo-amplitude condition and found no specific benefit of the higher-amplitude condition across the measured stroke outcomes [3]. This is one of the strongest placebo-controlled amplitude manipulations available anywhere in the motion-rich literature reviewed in this paper, because frequency was held constant while amplitude was varied between an active and a near-inert control condition.

The finding is a strong null result specific to the tested contrast. It should not be generalized to other vibration frequencies, other axes of delivery, other populations, or to other forms of motion beyond whole-body vibration as tested in this protocol.

9.3 Horizontal Vibration and Additional Null Comparative Evidence

The randomized controlled trial of whole-body vibration in the horizontal direction for stroke rehabilitation found no significant between-group benefit relative to its comparison condition [45]. This adds a second, independent null comparative result to the whole-body vibration literature, obtained using a different vibration orientation than the vertical placebo-amplitude study described in Section 9.2.

This trial does not report the physical dose in sufficient detail to support quantitative parameter modeling. A specific quantitative parameter rule, such as a minimum effective frequency or amplitude threshold, should not be constructed from this source alone, since its reporting of the delivered physical stimulus is incomplete relative to what quantitative dose-response modeling would require.

9.4 Meta-Analytic Evidence: Selective Impairment-Level Benefit

The systematic review and meta-analysis of whole-body vibration training in stroke reported pooled selective improvements in spasticity, motor function, and balance across the included trials, while pooled effects for gait, activities of daily living, and quality of life were null [7]. This pattern is consistent with the two individual randomized trials described above, both of which failed to demonstrate a specific benefit of their tested active vibration condition relative to a comparator [3, 45].

Impairment-level improvement of this kind, in measures such as spasticity or isolated motor function, should not be treated as proof of functional transfer. The same meta-analysis that reports these selective impairment-level gains also reports null pooled effects for the more functionally meaningful outcomes of gait, activities of daily living, and quality of life [7], and this distinction should be preserved rather than collapsed into a single summary claim of efficacy.

9.5 Parameter Moderation Without an Established Optimal Dose

Across the three whole-body vibration sources, outcome depends on protocol characteristics without a clear or established optimal parameter set. The meta-analysis reports exploratory moderation of pooled effects by frequency and by vibration orientation across the included trials [7]. The placebo-amplitude trial demonstrates directly that a larger tested amplitude did not produce a superior outcome to a smaller, near-inert amplitude at the same frequency [3]. The horizontal-direction trial demonstrates that a different orientation of delivery also failed to produce a significant benefit under its tested conditions [45].

Together these sources support protocol dependence: whole-body vibration outcomes vary with frequency, amplitude, and orientation. They do not support an inference of an optimal universal frequency, amplitude, axis, or overall dose for whole-body vibration, and no such optimal parameter set should be derived from this literature for use in the design of other motion-rich interventions.

10. Boating, Sailing, and Water-Based Motion Interventions

10.1 Sailing and Boating as Naturalistic Motion-Rich Interventions

Sailing and boating have been studied as naturalistic, hybrid motion-rich rehabilitation and participation contexts. A pilot study evaluated a virtual reality physical ride-on sailing simulator as a rehabilitation tool for recreational sports and community reintegration [46]. A study evaluated mindfulness-based therapeutic sailing for veterans with psychiatric and substance use disorders [11]. A feasibility and safety study evaluated sailing-based rehabilitation for rare skeletal disorders using wearable sensors and patient-reported outcomes [13].

Each of these interventions bundles vessel motion together with task performance, social interaction, environmental exposure, and, for the veteran and rare-disorder populations, structured recreational or rehabilitative programming. Sailing as studied in this literature should not be called a motion-specific treatment; it is a complex naturalistic intervention in which vessel motion is one component among several.

10.2 Current Clinical Evidence

The three sailing and boating sources report preliminary outcomes across skill transfer, psychological function, physical function, and participation domains. The virtual reality sailing simulator pilot study reported preliminary rehabilitation-relevant outcomes in the context of recreational sports and community reintegration [46]. The therapeutic sailing program for veterans reported psychological outcomes in the context of a mindfulness-based structured intervention [11]. The rare skeletal disorder feasibility study reported physical and participation outcomes alongside its feasibility and safety data [13].

These findings should be characterized as preliminary rather than as established clinical efficacy. Sample sizes are small, designs are largely uncontrolled or feasibility-oriented, and none of the three studies isolates vessel motion from the surrounding intervention. Reported outcomes should not be attributed to vessel motion specifically on the basis of these sources.

10.3 Tolerability and Motion Intolerance

The rare skeletal disorder feasibility and safety study provides a direct tolerability signal within the sailing literature: mild, transient nausea or dizziness was reported in 4 of the 8 participants during the sailing-based rehabilitation program [13]. This is a rare instance in the motion-rich literature reviewed in this paper where motion-related intolerance is reported explicitly as a study outcome rather than left unaddressed.

A population-wide adverse-event rate should not be inferred from this finding. The sample size is 8 participants, the population is a rare skeletal disorder group with its own clinical characteristics, and the finding should be read as a feasibility-study safety observation rather than as an estimate of motion intolerance in a general or SeaKing-relevant population.

10.4 The Unmeasured Vessel-Motion Problem

None of the three sailing and boating sources adequately quantifies vessel motion in six degrees of freedom, meaning the combination of roll, pitch, yaw, heave, sway, and surge that fully describes a vessel's physical motion, as the treatment exposure delivered to participants [46, 11, 13]. Session duration, route, and general time on the water are reported in this literature; sea state, vessel motion amplitude, frequency content, and axis-specific exposure generally are not.

Vessel roll, pitch, or heave dose should not be inferred from session duration, route, or time on water. These variables describe the structure of the intervention as delivered, not the physical motion stimulus received by the participant, and the two are not interchangeable. This gap is directly relevant to the SeaKing research program because it identifies vessel-motion characterization as an unmet methodological need in the existing sailing and boating literature, rather than as a problem that has already been solved by prior naturalistic studies.

11. Surfing and Board-Based Motion Interventions

11.1 Clinical Evidence from Surf-Based Interventions

The surf therapy literature examined in this review consists of a single study evaluating the effectiveness of surf therapy for children with disabilities [12]. Surfing is a hybrid motion-rich intervention in which wave and board motion occur alongside exercise, water immersion, instruction, and social engagement. The study reported within-group fitness improvements over the course of the surf therapy program, but did not find a statistically significant between-group superiority for overall fitness relative to a comparison condition of unstructured pool play [12].

This distinction should be preserved precisely. A within-group improvement over time is a different claim from a between-group comparative advantage, and the absence of the latter should not be minimized by emphasizing the former. The correct summary of this study is that participants improved on selected measures across the program, without surf therapy demonstrating superiority to the unstructured pool-play comparator on overall fitness. This single study should not be treated as motion-isolating evidence, and it does not permit outcomes to be attributed specifically to wave or board motion.

11.2 Motion-Specific Interpretation and Scientific Boundaries

The surf therapy study did not quantitatively characterize wave or board motion as a physical exposure, and it did not isolate that motion from the exercise, water immersion, instruction, and engagement that were delivered concurrently within the same sessions [12]. Wave and board motion in this literature therefore occupies the same evidentiary position as vessel motion in the sailing literature reviewed in Section 10: present within the intervention, plausible as a contributing factor, and not separated from the surrounding activity by the available study design.

Surf-based interventions should accordingly be understood as a naturalistic secondary domain that illustrates the same physical-stimulus characterization gap documented throughout this review, rather than as an independent source of motion-specific causal evidence. Observed outcomes in this literature should not be attributed to wave or board motion specifically.

12. Motion-Rich Interventions in POTS and Dysautonomia: Evidence Gap and Translational Implications

12.1 Current State of the Clinical Evidence

A systematic review of randomized trials for the treatment of postural orthostatic tachycardia syndrome (POTS) provides the evidence base examined for this population in Review 05 [4]. Within the evidence landscape audited for this review, no eligible controlled motion-rich POTS treatment study was identified.

This is a bounded conclusion about the evidence examined for this review, not a claim that no such study exists anywhere in the world literature or that motion-rich treatment would be ineffective in POTS. It states that, within the systematic review and the broader search conducted for Review 05, a controlled trial evaluating a motion-rich intervention such as rocking, vestibular rehabilitation, or vessel motion as a POTS treatment was not identified.

12.2 Existing Rehabilitation Approaches in POTS

The randomized POTS treatment literature identified by the systematic review includes pharmacologic strategies and nonpharmacologic strategies such as increased sodium intake, structured exercise training, compression garments, and device-based approaches [4]. These represent the existing evidence-based treatment landscape for POTS as characterized by that review.

None of these approaches should be relabeled as motion-rich treatment evidence. Generic exercise training, where present in the POTS literature, is not the same intervention class as the externally imposed or hybrid motion-rich interventions examined throughout this review, and it should not be presented as though it were. The same applies to any hydrostatic or aquatic therapy and to device-based approaches: these are distinct intervention classes from the motion-rich category this review defines, and conflating them would misrepresent both the POTS literature and the scope of this review.

12.3 Why the Evidence Gap Matters

The POTS evidence gap identified in Sections 12.1 and 12.2 [4] matters translationally because it stands in direct contrast to the motion-rich literature reviewed elsewhere in this paper. Controlled motion-specific manipulation has been demonstrated to be feasible and scientifically productive outside POTS: the cerebral palsy simulator trial manipulated motion directly using an ON-versus-OFF design [8], the controlled rocking studies specified motion as a quantitative experimental parameter [2], gaze-stabilization exercise has produced measurable recovery of dynamic visual acuity in unilateral vestibular hypofunction [17], and the whole-body vibration placebo-amplitude trial demonstrated that a physical motion parameter could be manipulated under double-blind conditions [3].

These non-POTS sources are used here only to establish that direct motion-response testing of this kind is scientifically feasible in principle. They are not POTS efficacy evidence, and they should not be used to infer that a motion-rich intervention would produce benefit in POTS, nor to infer benefit for the SeaKing intervention specifically. The POTS evidence gap therefore identifies an unresolved and directly testable clinical question rather than a basis for extrapolated efficacy.

13. Cross-Intervention Patterns in Motion-Rich Therapies

13.1 A Comparative View Across Intervention Domains

Physical motion-stimulus measurement varies substantially across the intervention domains reviewed in this paper. Many clinical studies report intervention structure, session duration, and procedural detail without quantitatively reporting the physical motion delivered. This pattern appears in the therapeutic horseback riding trial [1], the randomized platform-swing study [36], the therapeutic sailing program for veterans [11], the sailing-based rehabilitation feasibility study [13], the Ménière self-management trial [37], and the customized-versus-booklet vestibular rehabilitation trial in multiple sclerosis [23].

A minority of studies take the opposite approach. Controlled rocking protocols specify displacement and frequency as experimental parameters [2, 14], biomechanical studies quantify pelvis motion and mechanical-horse trunk kinematics [15, 16], instrumented observation measures horse-child movement coupling directly [19], and the whole-body vibration placebo-amplitude trial specifies frequency and amplitude precisely enough to construct a placebo condition [3]. Within the evidence reviewed here, quantitative physical-stimulus reporting is the exception rather than the rule.

13.2 The Recurring Structure of Motion-Rich Interventions

Representative examples across domains illustrate the same gap. The therapeutic horseback riding trial specifies session frequency and duration without quantifying the pelvic or trunk motion each participant received [1]. The therapeutic sailing and sailing rehabilitation studies specify program structure without quantifying vessel motion in six degrees of freedom [11, 13], and the surf therapy study for children with disabilities specifies session and program structure without quantifying wave or board motion [12]. The Ménière self-management trial and the gaze-stabilization study for dynamic visual acuity specify exercise protocols without quantifying head-movement kinematics [37, 17]. The multiple sclerosis fatigue and postural control trial and the customized-versus-booklet vestibulopathy trial specify treatment duration and content without quantifying the physical motion generated during exercise [9, 23].

When a study does not report a parameter, that parameter is unreported; it should not be inferred or reconstructed from the intervention's name or general structure.

13.3 Exceptions: Biomechanics, Rocking, and Vibration

A smaller set of rigorous human studies quantifies physical motion, kinematics, or vibration parameters directly for causal or biomechanical interpretation. The controlled rocking studies specify rocking axis, frequency, and duration and relate them directly to sleep and memory outcomes [2, 14].

Biomechanical work quantifies three-dimensional pelvis motion during therapeutic horse riding [15], frequency-, direction-, and support-specific trunk kinematics on a mechanical horse [16], and horse-child movement coupling during treatment [19]. The whole-body vibration placebo-amplitude trial specifies frequency and amplitude precisely enough to support a controlled amplitude contrast [3], and the whole-body vibration meta-analysis synthesizes reported vibration parameters across multiple trials [7].

A rocking frequency, a mechanical-horse trunk-kinematic parameter, and a whole-body vibration frequency describe physically different exposures measured by different conventions; none is a proxy for the others.

13.4 Consequences for Dose-Response Inference

Quantification of the physical stimulus is necessary but not sufficient for dose-response analysis, since the exposure itself must also vary across the conditions studied. Where motion is quantified and varied, as in the controlled rocking studies [2, 14], the biomechanical and mechanical-horse studies [15, 16], and the whole-body vibration trials [3, 7], within-study dose-response relationships can in principle be examined. Where motion is not quantified, as in the therapeutic horseback riding trial [1] and the sailing rehabilitation feasibility study [13], only intervention duration or activity labels are available, and these do not support dose-response inference regarding the physical motion stimulus itself.

A numerical cross-intervention dose equivalence, for example treating a defined duration of sailing as equivalent to a defined rocking frequency and duration, cannot be constructed from this heterogeneous and frequently incomplete literature.

14. Motion Characterization: The Missing Variable Across Motion-Rich Interventions

14.1 Physical Parameters and Response Variability

Physical protocol characteristics are associated with differences in response across several independently studied intervention classes. Controlled rocking studies show that differing rocking protocols produce materially different sleep and memory outcomes [2, 14]. Mechanical-horse studies show that trunk kinematic response depends on frequency, direction, and support condition [16]. The systematic review of perturbation-training mechanisms and parameters discusses how training characteristics relate to fall outcomes in older adults [44]. Whole-body vibration evidence shows outcome dependence on frequency, amplitude, and orientation, with a larger tested amplitude failing to outperform a smaller one in a placebo-controlled comparison [3, 7].

This convergent pattern, demonstrated independently within each domain rather than against a shared cross-domain metric, supports the general principle that physical protocol characteristics matter without supporting a single universal dose-response relationship across these mechanically distinct forms of motion.

14.2 Why Motion Characterization Matters

Participant state, posture, and active engagement shape the effective stimulus even when the nominal motion exposure is similar. Mechanical-horse trunk kinematic response varies with the support condition provided to the rider, so the same nominal simulator motion produces a different measured response depending on how the participant is supported [16]. The cerebral palsy simulator trial holds posture and seating relatively constant specifically so that the presence or absence of motion can be isolated as the experimental variable [8]. Vestibular rehabilitation exercises requiring repeated head movement depend on the participant's active engagement, not passive exposure to a fixed stimulus [17]. The customized-versus-booklet vestibular rehabilitation trial in multiple sclerosis shows that the structure and intensity of participant engagement can influence outcome independent of the underlying movement itself [23]. Support condition, active postural response, head movement, balance practice, and participant engagement therefore all contribute to what a nominally similar motion exposure actually delivers, and state and context effects should not be reduced to the physical waveform alone.

14.3 Lessons from Better-Characterized Motion Studies

The literature reviewed in this paper contrasts predictable and unpredictable motion exposures, and passively received against task-coupled movement. Controlled rocking delivers predictable, rhythmic, passive motion under a fixed protocol [2, 14]. Perturbation-based balance training delivers unpredictable disturbances by design, with the subacute stroke trial and the chronic stroke fall-prevention trial both structured around unanticipated postural challenge [18, 22]. Vestibular rehabilitation exercise requiring repeated head movement represents a third category: self-generated, task-coupled movement performed under participant control [17]. These three categories differ in predictability, in whether the participant or the apparatus initiates the movement, and in the cognitive and motor-planning demands involved; they should not be pooled as equivalent stimuli, and evidence from one should not be assumed to generalize to another.

14.4 Motion Characterization and Causal Inference

Because parameter sensitivity in Section 14.1 was demonstrated separately within each domain rather than against a shared cross-domain metric, the current human evidence does not establish a universal optimal motion prescription. SeaKing engineering parameters should not be extracted directly from these heterogeneous clinical and experimental protocols: the underlying studies were designed to answer distinct scientific and clinical questions in distinct populations using distinct motion-delivery apparatus, and their parameter sensitivities describe those specific systems rather than a generalizable prescription for a different motion platform.

15. Scientific Synthesis: What Motion-Rich Intervention Research Demonstrates

15.1 Tolerability Is a Separate Translational Outcome

Tolerability and adverse events should be evaluated as outcomes distinct from efficacy. Direct tolerability information appears in several sources: mild transient nausea or dizziness in 4 of 8 participants in the sailing-based rehabilitation feasibility study [13], the customized-versus-booklet vestibular rehabilitation trial in multiple sclerosis [23], the chronic stroke perturbation-based fall-prevention trial [22], and the randomized feasibility study of hippotherapy-based rehabilitation for children with cerebral palsy and autism spectrum disorder [47]. Most of these studies were not designed with adverse-event tracking as a primary outcome, so an unreported adverse event should not be read as proof of universal tolerability.

15.2 Motion Sickness and Susceptibility

Individual susceptibility to motion intolerance is consistent with observations from two sources. The sailing-based rehabilitation feasibility study reported nausea or dizziness in half of its small sample [13]. The slowly rocking bed sleep study excluded participants susceptible to motion sickness from enrollment, itself evidence that investigators regarded susceptibility as a relevant screening characteristic [14]. Neither source supports a prevalence estimate or a universal susceptibility threshold: the sailing finding describes a single small sample, and the rocking study's exclusion criterion describes a screening decision rather than a measured population rate.

15.3 Adverse Events in Rehabilitation Contexts

Several sources report safety-relevant observations specific to their own study context. The customized-versus-booklet vestibular rehabilitation trial and the chronic stroke perturbation-based fall-prevention trial both occur within populations at elevated fall risk, where intervention-related noninjurious falls are a relevant safety consideration during active balance training [23, 22]. Perturbation-based training protocols generally incorporate screening procedures intended to keep imposed disturbances within a tolerable range for each participant [22]. The randomized feasibility study of hippotherapy-based rehabilitation in cerebral palsy and autism spectrum disorder reports considerations relevant to fear-related exclusion from mounted or motion-based intervention [47]. The sailing-based rehabilitation feasibility study reports transient nausea and dizziness as symptom-level observations [13]. These are source-specific safety observations that should not be combined into a single pooled safety rate, since doing so would treat heterogeneous adverse events under different exposures and reporting conventions as measurements of the same underlying risk.

15.4 Implication for Future Motion-Rich Studies

Efficacy and response measurement should be paired with prospective tolerability and adverse-event tracking as a matter of study design [13, 23, 22, 47]. Existing tolerability data is inconsistent, incidentally reported, and not collected using shared instruments across studies, which limits what can be concluded about the safety profile of motion-rich interventions in general. No universal safety limit can be derived from these small, heterogeneous studies; future work, including SeaKing research, should treat tolerability as a prospectively measured outcome from the outset.

16. Response, Retention, Transfer, and Functional Interpretation

16.1 Immediate Response Is Not Durable Benefit

Across multiple intervention classes reviewed in this paper, an immediate or impairment-level response should not be treated as equivalent to durable functional benefit. The long-term follow-up of therapeutic horseback riding in ASD was designed specifically to examine what remained after the intervention period rather than relying on end-of-trial measurement alone [21]. The cerebral palsy simulator trial demonstrated a motion-specific effect on a single impairment-level outcome without addressing durability beyond the trial period [8]. The slowly rocking bed study showed that a physiological change observed during stimulation did not necessarily persist afterward [14]. The chronic stroke perturbation trial demonstrated retained reactive-balance capability without a corresponding reduction in real-world falls [22]. The customized-versus-booklet vestibular rehabilitation trial in multiple sclerosis showed that selected secondary gains did not extend to the primary outcome [23]. The traumatic brain injury vestibular rehabilitation trial showed loss of an initial between-group advantage at later follow-up [10]. The whole-body vibration meta-analysis showed selective impairment-level improvement without corresponding pooled functional gains [7]. Response, retention, transfer, and function are four distinct evidentiary claims, and evidence supporting one should not be presented as though it supports the others.

16.2 Examples of Retention

Selected effects have persisted beyond the immediate intervention period in several sources, with their specific outcome and follow-up boundaries preserved. The long-term follow-up of therapeutic horseback riding in ASD reported persistence of selected outcomes after the original trial concluded [21]. The simulated developmental horse-riding study in ASD reported that improved motor proficiency and sensory-integrative function were maintained at the authors' follow-up assessment [34]. The chronic stroke perturbation trial demonstrated that trained reactive-balance improvement was retained over the study's follow-up period [22]. The multiple sclerosis vestibular rehabilitation trial demonstrated improvements that changed minimally at 4-week follow-up [9]. The comparative vestibular rehabilitation and galvanic stimulation study in multiple sclerosis likewise demonstrated improvements that were approximately stable at 4-week follow-up [38]. The customized-versus-booklet vestibular rehabilitation trial in multiple sclerosis demonstrated selected secondary advantages that persisted at the 26-week assessment, while the primary Dizziness Handicap Inventory outcome remained nonsignificant [23]. Retention here is outcome-specific and study-specific, not uniform, since several of these same sources report outcomes that were not retained alongside the outcomes that were.

16.3 Examples of Nonretention

Direct examples of nonretention, and of retention simply not having been tested, appear across multiple domains and should not be conflated. The cerebral palsy simulator trial's motion-specific effect was demonstrated within the trial period; the trial did not test whether the effect persisted beyond it, so this is retention not tested rather than demonstrated nonretention [8]. The slowly rocking bed study demonstrated that its observed physiological change was largely confined to the stimulation window itself rather than producing a durable overnight or next-day effect [14]. The traumatic brain injury vestibular rehabilitation trial demonstrated the clearest form of nonretention in this review: a between-group advantage present at initial assessment was explicitly no longer significant at later follow-up [10]. These examples should not be generalized into a claim that all initial motion-rich responses are transient; Section 16.2 documents genuine retention elsewhere in this same literature, and the two patterns coexist.

16.4 Transfer to Real-World Function

Transfer to real-world function is present in some parts of this literature and absent or unresolved in others. Positive real-world transfer evidence is clearest in older adults, where meta-analytic evidence supports reduced fall and fall-injury rates following perturbation-based balance training [42, 44]. In chronic stroke, by contrast, the perturbation-based fall-prevention trial demonstrated retained reactive-balance capability without a significant reduction in community falls, and the stroke-specific systematic review situates this null or insufficient real-world fall evidence within the broader stroke literature [22, 43]. In whole-body vibration, the meta-analysis demonstrated selective impairment-level improvement alongside null pooled functional outcomes including gait and activities of daily living [7]. The same intervention category, perturbation-based balance training, therefore produces different real-world outcomes in different populations, and functional transfer demonstrated in one should not be generalized to another.

16.5 Implication for Interpreting Biomarkers and Proximal Responses

Physiologic, symptom, mobility, and other proximal responses documented throughout this review, including the neural-oscillation and memory changes in the controlled rocking literature [2, 14], the secondary symptom outcomes in the customized-versus-booklet vestibular rehabilitation trial [23], and the initial dizziness and mobility improvements in the traumatic brain injury vestibular rehabilitation trial [10], are scientifically valuable early-stage outcomes, but none should be described as proof of durable therapeutic efficacy on its own. A future physiological response observed in SeaKing research, whether autonomic, vestibular, or otherwise, should be interpreted using this same standard: a scientifically meaningful early-stage finding requiring subsequent evidence of retention, transfer, and functional benefit before it is described as a clinical treatment effect.

17. Cross-Intervention Synthesis and Translational Implications

17.1 What the Human Motion-Rich Literature Establishes

Multiple independently studied motion-rich human interventions can produce measurable effects, and imposed physical motion is causally active under at least some controlled conditions. In equine and mechanical-analogue research, the randomized controlled trial of therapeutic horseback riding in ASD demonstrated behavioral improvement relative to a control condition [1], the simulated developmental horse-riding study demonstrated improved motor proficiency and sensory-integrative function in ASD [34], the cerebral palsy simulator trial demonstrated a motion-specific contribution to a sitting-balance outcome using a moving-versus-nonmoving design [8], and the randomized controlled trial of hippotherapy on gross motor function in children with cerebral palsy demonstrated improvement relative to a comparison condition [48].

In controlled and rehabilitative motion research, the whole-night continuous rocking study demonstrated that a quantitatively specified passive motion exposure altered neural oscillations, sleep, and memory [2], the chronic stroke perturbation-based training trial demonstrated retained reactive-balance improvement [22], vestibular rehabilitation exercise requiring repeated head movement produced recovery of dynamic visual acuity in unilateral vestibular hypofunction [17], and vestibular rehabilitation improved fatigue and postural control outcomes in multiple sclerosis [9].

In vibration and acute vestibular research, the whole-body vibration meta-analysis demonstrated selective impairment-level improvement in stroke [7], simulator-based whole-body and visual-motion exposure added measurable benefit to customized rehabilitation for refractory dizziness [41], the randomized platform-swing study demonstrated that acute vestibular exposure produces a measurable, though in that instance null, behavioral test result [36], and the double-blind whole-body vibration trial demonstrated that amplitude could be manipulated as a controlled physical variable [3].

The specific outcomes, populations, and physical exposures differ substantially across these sources, and this body of evidence should not be read as establishing a universal positive effect direction or a common mechanism. Collectively, these studies show that motion-rich interventions can produce measurable human responses and that, in a subset of controlled designs, physical motion itself can be manipulated experimentally.

17.2 What It Does Not Establish

The same literature contains hard limits alongside the positive findings in Section 17.1. Null protocols exist: the randomized platform-swing study found no significant improvement in the specified independent-work behaviors following a single acute exposure [36], the slowly rocking bed study produced largely null whole-night sleep and memory findings [14], and the double-blind whole-body vibration trial found no specific benefit of the tested higher-amplitude condition [3], reinforced by the whole-body vibration meta-analysis's null pooled effects for gait, activities of daily living, and quality of life [7]. Active comparators can perform similarly to the primary intervention: the comparative effectiveness study found that therapeutic riding and mindfulness produced comparable improvement in adolescents with autism [20], and the customized-versus-booklet vestibular rehabilitation trial found no superiority of the more intensive program on its primary outcome [23]. Functional transfer can fail, as in the chronic stroke perturbation trial's retained reactive-balance improvement without a significant reduction in community falls [22]. Direct behavioral null findings exist within controlled ASD equine research specifically [29], and outcome effects are heterogeneous across the equine-assisted therapy literature broadly [5] and the vestibular rehabilitation literature synthesized in systematic review [6]. These limits bound what Section 17.1 supports without implying motion is irrelevant.

17.3 A Continuum From Complex Natural Intervention to Controlled Physical Stimulus

The interventions reviewed in this paper can be arranged along a conceptual continuum of increasing experimental control, not increasing biological similarity. At the complex end, therapeutic horseback riding [1], therapeutic and rehabilitative sailing [11, 13], and surf therapy [12] bundle physical motion with social, task, and environmental components that have not been experimentally separated. Mechanical analogues occupy an intermediate position: the simulated developmental horse-riding program in ASD [34] and the direct live-horse-versus-simulator comparison [32] preserve a riding-like exposure while reducing some of the variability associated with a live animal. Motion-specific manipulation increases resolution further, as in the cerebral palsy simulator's ON-versus-OFF design [8]. Tightly controlled physical-stimulus studies occupy the far end, including the quantitatively specified rocking protocols [2, 14] and the placebo-amplitude whole-body vibration trial [3]. Movement-based rehabilitation, exemplified by vestibular rehabilitation exercise [17] and simulator-based vestibular desensitization [41], represents a parallel clinical track in which repeated movement is embedded within a structured therapeutic program rather than isolated as an experimental variable. This continuum is a conceptual organizing structure, not proof that the interventions positioned along it are equivalent or share a single underlying mechanism.

17.4 ASD and POTS: Deliberately Asymmetric Translational Evidence

The evidence bases for the two primary populations examined in this review are deliberately asymmetric, and that asymmetry should be stated plainly rather than minimized. ASD has a substantive direct human intervention literature: randomized controlled trials of therapeutic horseback riding [1], a randomized controlled study of a standardized equine-assisted therapy program [26], a replication pilot trial [28], meta-analytic evidence on equine assisted services and social skills [30], and systematic review and meta-analysis of equine-assisted activities and therapies more broadly [5], together with a direct experimental behavioral null finding [29]. POTS, by contrast, has an established randomized pharmacologic and nonpharmacologic treatment literature that does not include an identified controlled motion-rich treatment [4]. This asymmetry describes the depth of the direct intervention literature in each population; it does not imply that the mechanistic plausibility of a motion-rich approach is weaker in POTS, since the POTS evidence gap identified in Section 12 reflects an absence of conducted trials, not a demonstrated absence of biological plausibility.

17.5 Why Direct Characterization of Natural Multidimensional Motion Is Scientifically Justified

Two recurring observations established across this review, taken together, justify direct physical-stimulus characterization as a next scientific step. First, physical motion can be quantitatively measured with rigor when investigators choose to do so: controlled rocking protocols specify displacement and frequency [2, 14], biomechanical studies quantify pelvis motion during horse riding and trunk kinematics on a mechanical horse [15, 16], instrumented observation quantifies horse-child movement coupling [19], and the whole-body vibration trial and meta-analysis specify frequency and amplitude precisely [3, 7]. Second, many of the clinically relevant intervention wrappers examined in this review leave that same physical motion undefined: the therapeutic horseback riding trial does not quantify the movement delivered to each rider [1], and the sailing-based rehabilitation feasibility study does not quantify vessel motion in six degrees of freedom [13]. This combination, demonstrated measurability alongside a recurring characterization gap, is the scientific rationale for direct measurement of natural multidimensional motion; it establishes only that the measurement itself is a justified and unmet scientific need, not a future engineering solution or optimal waveform.

17.6 SeaKing-Specific Inference Boundaries

The representative audited evidence reviewed throughout this paper, including the therapeutic horseback riding trial [1], the cerebral palsy simulator ON-versus-OFF trial [8], the controlled rocking literature [2], the sailing rehabilitation feasibility study [13], the whole-body vibration placebo-amplitude trial [3], and the POTS treatment systematic review [4], supports the translational boundary that governs this review's conclusions: the existing evidence supports the biological and experimental plausibility of motion as a variable worth direct testing and the feasibility of direct controlled testing of physical motion exposure. It does not support SeaKing efficacy, a common mechanism linking the interventions reviewed in this paper, or an optimal motion dose for any future platform. No source cited in this subsection, or elsewhere in this review, may be read as direct evidence that SeaKing works; this review establishes scientific rationale for further study, not the efficacy of SeaKing Solace.

18. Conclusions, Evidence Gaps, and Bridge to Controlled Motion Research

18.1 Principal Conclusions

Review 05 supports the following principal conclusions, drawn directly from the evidence reviewed in the preceding sections. Motion-rich human interventions can produce measurable effects, as demonstrated by the therapeutic horseback riding trial [1], the simulated developmental horse-riding study in ASD [34], and the cerebral palsy simulator ON-versus-OFF trial [8]. Physical motion can itself function as a controlled experimental variable, as demonstrated by the whole-night continuous rocking study [2].

Null and mixed findings occur throughout this literature, as demonstrated by the slowly rocking bed study [14], the randomized platform-swing study [36], and the direct behavioral null finding in the equine ASD literature [29]. Package-level clinical benefit has been demonstrated across several populations using movement-based rehabilitation, as in vestibular rehabilitation for peripheral vestibular disorders [17] and the systematic review of vestibular rehabilitation efficacy across neurologic disorders [6].

Selective impairment-level benefit without uniform functional transfer has been demonstrated in whole-body vibration [7], and a direct placebo-amplitude manipulation has shown that a larger tested vibration amplitude did not outperform a smaller one [3]. Reactive motor learning through perturbation-based training has been demonstrated to reduce falls in selected older-adult populations [42, 44]. Equine-assisted interventions in ASD produce measurable but heterogeneous effects across outcome domains [5], and a direct, published evidence gap exists for motion-rich treatment of POTS [4].

This recap represents the frozen principal conclusions of Review 05 as established across Sections 1 through 17; it introduces no new conclusion and strengthens no claim beyond what those preceding sections support.

18.2 Major Evidence Gaps

Four major evidence gaps recur across this review. Repeated-dose swing efficacy in ASD remains unresolved, since the direct evidence base consists of one acute feasibility study and one acute randomized null trial, with no repeated-session efficacy study identified [35, 36]. Vessel-motion characterization remains an unmet need across the sailing and boating literature, where six-degree-of-freedom motion is not adequately quantified in any of the reviewed sources [13]. Direct controlled motion-rich treatment evidence for POTS remains absent from the systematic review examined for this population [4]. Broader physical-stimulus and parameter reporting limitations recur across most of the naturalistic clinical literature reviewed in this paper, in contrast to the smaller set of studies, including the mechanical-horse biomechanics literature, that report physical parameters explicitly [16].

These are published evidence gaps, not evidence of ineffectiveness, and should not be filled by inference from discovery-stage materials. The MiraColt platform discussed in Section 4.6 is one example: its current status is an evidence gap regarding peer-reviewed clinical efficacy and should continue to be described in exactly those terms.

18.3 Review 05 as a Bridge to Controlled Motion Research

The evidence reviewed in this paper, taken as a whole, provides a scientific rationale for direct measurement and experimental separation of physical motion within complex human experiences. The cerebral palsy simulator trial demonstrates that motion can be manipulated as an isolated experimental variable within a clinical population [8]. The controlled rocking studies demonstrate that motion can be specified quantitatively and related to measurable physiological and cognitive outcomes [2, 14]. Biomechanical work demonstrates that motion can be characterized in detail using established methods [15, 16]. The whole-body vibration placebo-amplitude trial demonstrates that a physical parameter can be isolated under double-blind conditions [3]. The sailing rehabilitation feasibility study demonstrates both the promise and the current limitation of naturalistic motion-rich research, since it studies a genuine marine motion exposure without adequately quantifying that exposure [13]. The POTS treatment systematic review demonstrates a clinical population with an unresolved motion-rich treatment question [4].

Direct POTS efficacy and SeaKing-specific efficacy remain unestablished by any source reviewed in this paper. This review's role ends at the boundary it has defined throughout: direct measurement and experimental study of natural multidimensional motion is scientifically warranted, while how that motion should be engineered, measured, or delivered on a controlled platform, and whether a specific SeaKing intervention is efficacious, are questions reserved for the subsequent reviews in this series.

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