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REVIEW PAPER

Physical activity in autism: a critical review and Dual-Outcome Model of motor gains and psychophysiological load

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Abstract

Physical activity is widely promoted as a beneficial component of intervention for children with autism spectrum disorder, with numerous studies demonstrating improvements in motor coordination, balance, and strength. However, emerging evidence suggests that motor gains may not fully reflect the child's overall experience during activity. This critical review examines potential negative or paradoxical outcomes that may accompany physical activity participation despite measurable improvements in motor skills. Drawing on sensory processing research, exercise physiology, and findings from related developmental conditions, the review identifies several pathways through which activity may impose hidden burdens. These include sensory overload, emotional dysregulation, performance-related anxiety, autonomic strain, fatigue, and increased vulnerability associated with co-occurring attention deficits, motor coordination difficulties, or dyspraxia. Methodological limitations in the existing literature, such as a focus on positive outcomes, underreporting of adverse events, and insufficient characterization of participant heterogeneity, further obscure these risks. To address this gap, the Dual-Outcome Model is proposed, emphasizing that motor competence and psychophysiological load represent distinct developmental trajectories that may diverge during intervention. Recognizing this duality underscores the importance of individualized program design, comprehensive monitoring, and multidimensional assessment to ensure that physical activity supports both motor development and overall well-being. This perspective encourages more balanced, child-centered approaches to physical activity in autism research and clinical practice.

Keywords: Dual-Outcome Model, psychophysiological load, sensory processing, physical activity interventions, autism spectrum disorder

Introduction

Physical activity (PA) and structured motor interventions have become central components of rehabilitation and educational programs for children with autism spectrum disorder (ASD). Over the past two decades, a substantial body of research has demonstrated that PA contributes to improvements in fundamental motor skills, coordination, balance, and physical fitness in this population [1-4]. Meta-analytic evidence consistently reports moderate to large effects on locomotor abilities, object-control skills, muscular strength, and cardiorespiratory fitness following

exercise-based interventions [2,5,6]. Consequently, PA is widely regarded as an accessible and effective therapeutic strategy and is increasingly incorporated into early intervention frameworks, school curricula, and physiotherapy practice.

Beyond motor outcomes, PA has also been associated with secondary benefits in social engagement, emotional regulation, and aspects of cognitive functioning [4,7]. These findings have contributed to a dominant narrative in which PA is frequently framed as broadly beneficial and generally low risk for children with autism spectrum disorder.

However, this perspective has developed alongside relatively limited scrutiny of whether observable motor improvements consistently reflect positive experiential or regulatory outcomes.

ASD is characterized by neurodevelopmental features that may substantially shape responses to PA, including atypical sensory processing, altered autonomic regulation, and increased vulnerability to emotional dysregulation [8-10]. While repetitive practice and task exposure can facilitate motor learning, the sensory, emotional, and physiological demands of many PA contexts may impose considerable internal load. Environmental unpredictability, social interaction demands, and performance expectations may elicit heightened stress responses, even when motor performance appears adequate. Evidence from related developmental conditions suggests that motor gains can coexist with fatigue, anxiety, or emotional strain during training [11], raising concerns about the assumption that improved performance necessarily reflects improved well-being.

Physiological studies further complicate interpretation of PA benefits. Research indicates that many autistic children exhibit atypical autonomic responses during exercise, including reduced heart rate variability, heightened sympathetic activation, and delayed recovery following exertion [9,12]. These findings suggest that the internal physiological cost of activity may be elevated even when external task demands are comparable to those of typically developing peers. Similarly, sensory sensitivities may render common PA environments challenging, increasing the risk of overstimulation or withdrawal despite preserved task execution [13].

Methodological limitations within the current literature further obscure these dynamics. Intervention studies and reviews largely prioritize performance-based motor outcomes, with limited attention to emotional, sensory, or physiological responses during participation [14-16]. As a result, motor improvements may mask concurrent stress or dysregulation, creating an incomplete picture of intervention impact.

Aim of the work

The aim of this study is to critically re-examine the assumption that all forms of PA are inherently beneficial for children with ASD by analyzing the interaction between motor improvements and exercise-related psychophysiological demands. This review introduces the Dual-Outcome Model, which conceptualizes motor competence and psychophysiological load as partially independent yet interacting developmental trajectories. By adopting this framework, the study seeks to support more individualized, evidence-balanced, and child-centered approaches to PA in autism research and clinical practice.

In this review, the terms “negative” or “paradoxical” outcomes do not imply that PA is inherently harmful or contraindicated for children with ASD. Rather, they refer to situations in which motor improvements coexist with increased internal load, sensory overstimulation, emotional dysregulation, fatigue, or reduced subjective well-being. These responses reflect mismatches between task demands and individual regulatory capacity rather than pathological deterioration. Clarifying this distinction is essential to avoid misinterpretation and to promote balanced, individualized intervention design.

Methods

This study was conducted as a critical narrative review examining the effects of PA interventions in children with ASD, with particular emphasis on the coexistence of motor gains and psychophysiological load. The methodological approach was intentionally interpretative rather than systematic, allowing conceptual integration across motor, sensory, emotional, and physiological domains and facilitating identification of underreported risks and methodological blind spots in the existing literature.

A comprehensive literature search was performed using PubMed and MEDLINE, Scopus, Web of Science, and Google Scholar. In addition, targeted manual searches of leading journals in autism research, pediatric rehabilitation, developmental neurology, exercise science, and adapted PA were conducted. Reference lists of key articles were screened to identify additional relevant publications. The search strategy combined keywords related to autism spectrum disorders, PA,

exercise, motor development, sensory processing, psychophysiological stress, emotional regulation, fatigue, anxiety, and rehabilitation.

The initial database search yielded approximately 312 records. After removal of duplicates and preliminary screening for relevance, 148 full-text articles were reviewed. Of these, 92 studies directly informed the core thematic synthesis of motor outcomes, psychophysiological responses, and methodological considerations. As this was a narrative review, formal quality scoring and PRISMA flow documentation were not applied; however, selection decisions were guided by relevance to the conceptual aims of the review.

The review included peer-reviewed articles published between 2000 and 2024 and written in English. This time frame reflects the period of expanded research on structured PA interventions using contemporary diagnostic frameworks for ASD.

Studies were eligible if they examined children or adolescents with ASD and investigated PA, exercise, or motor-based interventions with reported outcomes related to motor performance, physical fitness, behavioral regulation, emotional functioning, sensory responses, or physiological regulation. Quantitative, qualitative, and mixed-methods studies were considered, along with reviews that provided empirically grounded conceptual insights. Studies focusing exclusively on adult populations, lacking relevant outcome measures, or relying on non-peer-reviewed sources were excluded. Articles in which PA effects could not be clearly distinguished from pharmacological or purely educational interventions were also excluded.

Data extraction focused on participant characteristics, intervention type and intensity, contextual features of activity environments, outcome measures, and reported benefits or adverse responses. Findings were synthesized thematically rather than quantitatively, with particular attention to discrepancies between observed motor improvements and indicators of sensory, emotional, or physiological strain. Methodological limitations, including underreporting of adverse effects, insufficient characterization of participant heterogeneity, reliance on performance-based motor assessments, and limited follow-up duration, were critically considered.

As a narrative review, this study is subject to potential selection bias and does not include formal quality scoring. However, this approach was deliberately chosen to support theoretical integration and to provide a more balanced interpretation of PA outcomes in children with ASD, beyond motor performance alone.

Study selection involved independent screening of titles and abstracts for conceptual relevance to motor outcomes and psychophysiological responses. Articles were included when they contributed empirical data or theoretically grounded discussion relevant to either trajectory of the proposed model. Discrepancies in inclusion decisions were resolved through consensus discussion among the authors. Thematic synthesis was conducted iteratively, with emerging patterns grouped under motor competence, sensory-emotional load, autonomic regulation, comorbidity modulation, and methodological blind spots.

Literature review results

Overview of motor skill gains in ASD interventions

A substantial body of empirical evidence demonstrates that PA interventions produce meaningful improvements in motor performance in children with ASD. Meta-analytic findings [2] report moderate to large effects of structured PA on fundamental motor skills, including both locomotor and object-control abilities, with pooled effect sizes exceeding 0.70 across controlled trials. These findings indicate that motor skill acquisition in autistic children is responsive to targeted PA and training, even in the presence of underlying neurodevelopmental differences.

Recent systematic reviews further corroborate these conclusions. Research evidence showed that PA interventions lead to significant improvements in gross motor coordination, balance, bilateral coordination, and movement fluency [5]. Importantly, gains were observed across both outcome-oriented measures, such as standardized motor assessments, and process-oriented indicators, including movement quality and postural control. Similarly, another study reported that motor-focused interventions reliably improve motor competence and may be accompanied by secondary benefits in social and communicative domains, suggesting that enhanced motor engagement can influence broader aspects of functioning [4].

Proposed mechanisms underlying these motor gains largely reflect principles of motor learning and physical conditioning. Repetitive, task-specific practice supports neuromuscular coordination, sensorimotor integration, and motor planning, enabling children with ASD to acquire and refine movement patterns over time. Improvements in balance and coordination following structured training further suggest enhanced efficiency within cerebellar-vestibular and

sensorimotor systems, which are commonly implicated in autism-related motor difficulties [8,17]. From a fitness perspective, PA interventions have been shown to improve muscular strength, endurance, and aerobic capacity in autistic youth [3]. These fitness gains may indirectly support motor performance by reducing fatigue, improving postural stability, and facilitating sustained engagement during motor tasks.

Taken together, the available evidence robustly supports the conclusion that PA interventions are effective in enhancing motor competence in children with ASD. Motor improvements are consistently observed across diverse intervention types and outcome measures, establishing PA as a reliable means of promoting motor skill development. However, while these findings provide a strong foundation for PA-based intervention, they primarily reflect performance-level outcomes and do not address the broader experiential or regulatory demands associated with participation. As such, motor gains alone offer an incomplete account of intervention impact, underscoring the need to examine PA effects beyond motor proficiency.

Potential negative pathways in PA interventions for children with ASD

Although PA interventions often lead to improvements in motor performance, several neurodevelopmental characteristics of ASD may predispose some children to adverse or paradoxical responses during participation. These responses arise through multiple, partially overlapping pathways involving sensory processing, emotional regulation, anxiety, and physiological stress.

Sensory overload represents one of the most prominent pathways. Many autistic children exhibit heightened sensitivity to auditory, tactile, proprioceptive, or vestibular input [13]. PA environments such as gyms, playgrounds, or group classes are frequently characterized by noise, rapid movement, physical contact, and spatial unpredictability, which can exceed sensory tolerance thresholds. Clinical observations from occupational and physiotherapy contexts document episodes of withdrawal, agitation, or behavioral escalation when sensory demands intensify during activity, even when children demonstrate adequate task execution under controlled conditions [18]. Reduced sensory gating and limited habituation to repeated stimuli further increase vulnerability during sustained or high-intensity sessions [17,19].

Emotional dysregulation constitutes a closely related pathway. Children with ASD often experience difficulty modulating arousal in situations involving novelty, unpredictability, or physical challenge [10,20]. Structured PA frequently requires rapid task transitions, compliance with instructions, and social interaction with peers or instructors. When these demands exceed regulatory capacity, children may exhibit frustration, irritability, shutdown, or behavioral outbursts. Clinical case descriptions indicate that such responses can occur concurrently with observable improvements in motor proficiency, suggesting that performance-based assessments may not fully capture the emotional experience of participation.

Anxiety further contributes to negative responses, particularly in evaluative or socially demanding contexts. Many autistic children experience heightened anxiety when faced with performance expectations, time constraints, or social comparison [21]. Group-based activities may amplify these stressors due to ambiguous social cues and difficulty predicting others' behavior. Behavioral clinicians frequently report children who perform competently in structured motor tasks yet display avoidance or distress in less predictable activity settings, highlighting the role of context in shaping engagement.

Physiological stress represents an additional pathway. Autonomic studies indicate that many autistic children show elevated heart rates, reduced heart-rate variability, and delayed recovery during and after exercise, reflecting increased sympathetic activation and reduced physiological flexibility [9,12]. Exercise physiology research demonstrates that children with ASD may experience greater cardiorespiratory strain than typically developing peers at comparable workloads, indicating a higher internal cost of activity. Over time, cumulative fatigue and physiological stress may negatively affect attention, mood, and motor coordination, increasing the likelihood of disengagement or injury [22].

Together, these pathways illustrate how PA participation may impose sensory, emotional, and physiological demands that are not readily apparent through motor outcomes alone. Integrating these mechanisms into a unified framework provides a more complete understanding of individual variability in PA responses among autistic children.

Co-occurring conditions: ADHD, dyspraxia, and developmental coordination disorder (DCD)

Comorbidity is widely recognized as the norm rather than the exception in ASD, and co-occurring conditions substantially influence how children respond to PA interventions. Epidemiological studies indicate that up to 80% of autistic children exhibit clinically significant symptoms of attention-deficit hyperactivity disorder, while approximately half meet diagnostic criteria for developmental coordination disorder [11,23]. These conditions introduce additional cognitive, emotional, and physiological demands that shape engagement, tolerance, and adaptation to PA.

Children with attention-deficit hyperactivity disorder often experience particular challenges during structured PA due to difficulties with sustained attention, impulse control, and behavioral regulation. Tasks requiring rule adherence, sequencing, or prolonged focus may lead to rapid disengagement or overstimulation, especially in environments rich in sensory or social stimuli. These attentional and regulatory demands can elevate arousal and frustration during activity, increasing internal load even when repeated practice leads to observable improvements in motor skill execution.

For children with developmental coordination disorder, the primary challenge lies in inefficient motor execution and increased energetic cost of movement. These children frequently fatigue more quickly, rely on compensatory strategies, and experience reduced motor self-efficacy following repeated difficulty. Although structured PA can improve coordination and motor performance, the elevated effort required to perform tasks may contribute to heightened fatigue, emotional stress, or avoidance, particularly during complex or prolonged activities.

Dyspraxia represents a related but distinct contributor to PA response. Impairments in motor planning and sequencing increase cognitive workload during movement, requiring greater attentional resources and processing time, especially when tasks are novel or multi-step. As a result, PA may be experienced as mentally demanding or exhausting even when outward performance improves, reinforcing the need to consider cognitive load alongside motor outcomes.

Taken together, these comorbid conditions modulate how autistic children experience PA interventions. When attentional, coordination, or planning difficulties are not adequately considered, improvements in motor performance may be overinterpreted as uniformly positive outcomes. Incorporating comorbidity profiles into assessment and intervention planning is

therefore essential for aligning PA programs with each child's regulatory capacity and overall well-being.

Increased risk of injury or motor regression

Children with ASD may be at elevated risk for exercise-related injury due to motor coordination challenges, delayed reaction times, joint instability, or reduced proprioceptive awareness [8]. High-intensity or rapid-sequence PA activities may exacerbate these vulnerabilities. Furthermore, if PA intensity or complexity exceeds the child's optimal learning threshold, motor regression or reinforcement of inefficient movement patterns may occur even while short-term performance appears to improve.

Only a handful of studies explicitly report injuries or regressions, likely due to under-monitoring. The possible disconnect between skill acquisition and functional motor quality underscores the need for caution in interpreting the success of PA interventions (Table 1).

Table 1. Pathways linking PA participation to potential negative outcomes in children with autism spectrum disorder

Pathway	Mechanism	Potential outcomes
Sensory overload	Hypersensitivity, unpredictable stimuli	Withdrawal, agitation, reduced engagement
Emotional dysregulation	Difficulty modulating arousal	Outbursts, refusal, negative affect
Performance anxiety	Evaluation pressure, social comparison	Avoidance, somatic symptoms, reduced participation
Autonomic imbalance	Reduced heart rate variability (HRV), inefficient physiological response	Fatigue, physiological stress, irritability
Comorbid ADHD/DCD	Attention/motor coordination deficits	Poor learning transfer, increased frustration
Injury or regression	Motor instability; excessive task demands	Acute injuries, reinforced maladaptive patterns

Notes: The framework presented in Table 1 is derived from an integrative review of sensory, emotional, autonomic, and motor control literature [9,10,12,13].

Case-based evidence and indirect evidence from related fields

Although direct reports of adverse outcomes in PA interventions for children with ASD are limited, several strands of indirect evidence suggest that motor improvements may coexist with

psychological or physiological strain. These observations, drawn from case reports, adjacent clinical populations, and exercise physiology, support the plausibility of the negative pathways described earlier.

Clinical case descriptions in occupational therapy, physiotherapy, and behavioral intervention contexts frequently document episodes of sensory overload, withdrawal, or behavioral escalation during structured motor or play-based activities [18]. While such events are often interpreted as transient behavioral challenges rather than adverse effects, they indicate that sensory, social, and motor demands associated with PA may exceed individual tolerance thresholds. The same study [18] described children disengaging abruptly from motor tasks when auditory or tactile stimulation increased, despite adequate skill acquisition under controlled assessment conditions. These observations highlight a discrepancy between motor performance in structured settings and emotional experience during real-world activity.

Additional indirect evidence comes from studies of children with developmental coordination disorder and attention-deficit/hyperactivity disorder, conditions that frequently co-occur with ASD. Children with developmental coordination disorder often demonstrate motor gains following intensive training while simultaneously reporting increased frustration, fear of failure, or avoidance behaviors. Similarly, youth with attention-deficit/hyperactivity disorder participating in exercise programs may show improved physical fitness alongside heightened overstimulation or emotional dysregulation during high-intensity sessions. Given the high comorbidity rates, these patterns provide relevant insight into how autistic children may respond to PA demands.

Exercise physiology studies further suggest disproportionate internal strain during PA. A study reported higher heart rates and delayed autonomic recovery in autistic children performing cycling exercise at workloads matched to typically developing peers, indicating elevated internal load despite equivalent external demands [12]. Such findings align with caregiver reports of chronic fatigue and stress during periods of increased activity participation [9,22].

Evidence from social participation contexts adds another dimension. Group-based motor activities, including martial arts and team sports, have been associated with motor improvements but also increased social anxiety in some children, particularly those with limited social competence or difficulty interpreting interpersonal cues [21]. Clinicians often describe children

who perform well in structured motor tasks yet display avoidance or distress in unpredictable or socially complex activity settings.

Collectively, these indirect observations reinforce the notion that motor gains do not necessarily reflect positive global outcomes. Instead, improvements may occur alongside unmeasured sensory, emotional, or physiological strain, underscoring the need for more comprehensive evaluation of PA interventions in ASD.

It is important to note that much of the evidence described in this section is indirect or extrapolated from adjacent developmental or physiological research. Direct longitudinal studies simultaneously measuring motor gains and psychophysiological load in ASD remain limited. Accordingly, several interpretations proposed here should be understood as theoretically grounded hypotheses requiring empirical verification rather than definitive causal conclusions.

Gaps in research and methodological blind spots

Despite robust evidence supporting motor improvements following PA interventions in children with ASD, significant gaps remain in how intervention outcomes are conceptualized and evaluated. Most studies prioritize performance-based motor outcomes while providing limited insight into the sensory, emotional, or physiological demands associated with participation. Adverse responses, including dysregulation, fatigue, or avoidance, are infrequently documented, and variability in individual responsiveness is often underexplored. As a result, the literature offers an incomplete account of intervention impact, emphasizing observable gains while overlooking potential costs.

A further limitation lies in the narrow scope of outcome assessment. Standardized motor tests are widely used as primary indicators of success, yet they capture only one dimension of adaptation. Measures reflecting psychophysiological load, such as autonomic responses, perceived exertion, emotional regulation, or post-session recovery, are rarely incorporated. This imbalance constrains understanding of how motor improvements are achieved and sustained and limits the ability to identify children for whom PA may be poorly tolerated despite apparent progress.

These gaps have direct implications for both clinical practice and research design. Clinicians should interpret motor gains within a broader context that includes indicators of stress, engagement, and recovery rather than assuming that improved performance reflects global benefit.

Researchers are encouraged to adopt multidimensional outcome frameworks, integrate monitoring of adverse responses, and include longitudinal follow-up to assess sustainability and well-being over time. Policymakers and program developers should likewise move beyond motor proficiency as the sole benchmark of effectiveness and support guidelines that promote individualized, regulation-sensitive PA programming.

Addressing these gaps is essential for advancing PA interventions that are not only effective in improving motor skills but also responsive to the diverse regulatory capacities of autistic children. A shift toward integrated evaluation will enhance both scientific rigor and clinical relevance, ensuring that PA supports long-term participation and overall well-being rather than short-term performance alone.

Proposal of a new framework: the dual-outcome model

To advance a more balanced and multidimensional understanding of PA interventions in ASD, we propose the Dual-Outcome Model, a conceptual framework designed to capture the simultaneous yet partially independent developmental trajectories activated by PA. Existing literature has largely emphasized positive motor outcomes, often framing PA as an unequivocally beneficial intervention [2,5,24]. However, accumulating psychophysiological evidence suggests that autistic children may experience disproportionate sensory, emotional, or autonomic strain during activity, even when clear improvements in motor performance are observed [9,12,24]. The Dual-Outcome Model integrates these parallel influences to provide a more comprehensive interpretation of PA effects.

Conceptually, the Dual-Outcome Model aligns with established load-recovery principles in exercise physiology, which recognize that adaptation occurs when external demands are balanced by sufficient recovery capacity. It also resonates with stress-adaptation and allostatic load models, wherein cumulative physiological strain may produce adaptive or maladaptive outcomes depending on individual regulatory thresholds. However, unlike traditional models that focus primarily on physiological adaptation, the present framework integrates sensory, emotional, autonomic, and cognitive load dimensions specific to ASD, thereby extending load-based theory into neurodevelopmental intervention contexts (Figure 1).

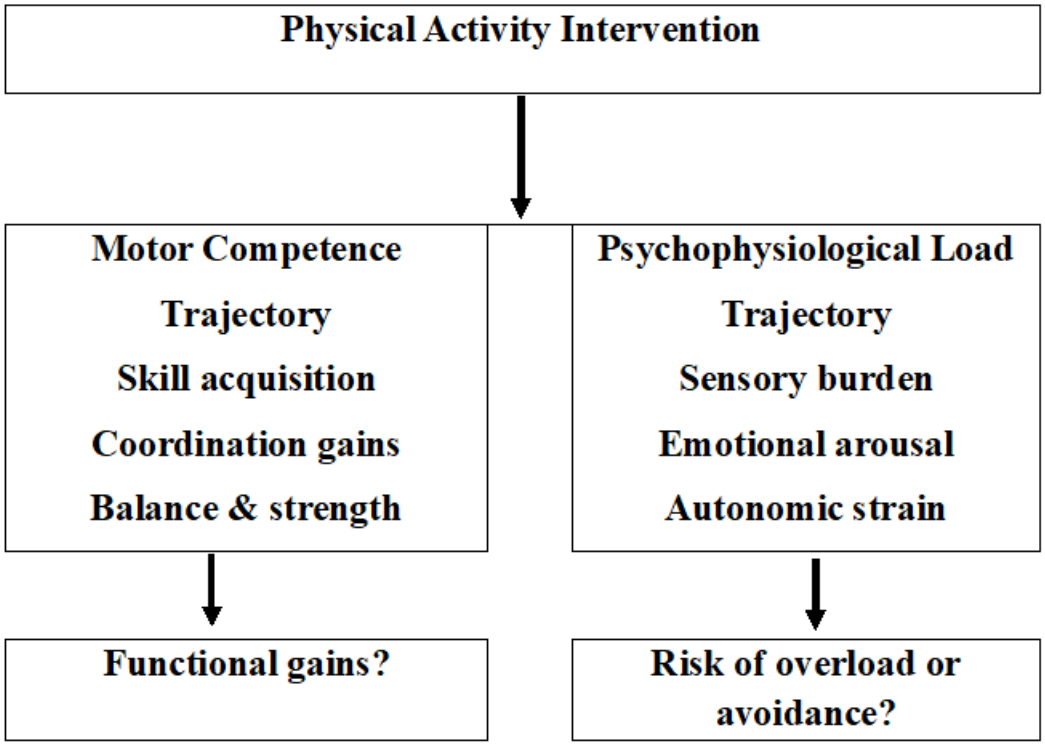

Figure 1. Conceptual diagram of the Dual-Outcome Model developed by the authors based on the literature reviewed in this study [9,10,13,21]

Notes: PA simultaneously activates the Motor Competence Trajectory and a Psychophysiological Load Trajectory. While motor gains may increase progressively with structured training, psychophysiological load may stabilize, decrease with adaptation, or increase when demands exceed regulatory capacity. These trajectories may diverge over time, underscoring the need for independent monitoring of both performance and internal load indicators in clinical and research settings.

Within this framework, PA elicits two concurrent trajectories. The first, the Motor Competence Trajectory, reflects well-documented improvements in gross and fine motor skills following structured PA interventions. Children commonly demonstrate enhanced locomotor abilities, improved balance and postural control, increased muscular strength, and more refined coordination of complex movements. These gains are attributed to repetitive practice, enriched sensorimotor input, task-specific training, and improvements in neuromuscular efficiency [8,17]. As a result, many children show improved performance on standardized motor assessments and enhanced motor learning, sometimes with evidence of skill retention or transfer across tasks. This

trajectory constitutes the primary focus of most intervention studies and often serves as the main indicator of program efficacy.

Running in parallel is a second, less frequently examined pathway, the Psychophysiological Load Trajectory. This trajectory encompasses the cumulative sensory, emotional, autonomic, and cognitive demands imposed by PA participation. Many autistic children exhibit heightened sensory reactivity, reduced sensory gating, and limited tolerance for unpredictable stimulation [13,18,25]. PA environments characterized by noise, movement, tactile contact, and rapid transitions may therefore generate high sensory load. At the same time, the social and performance-related demands of structured activities introduce cognitive and emotional stressors, including the need to follow instructions, adapt to novel tasks, and manage peer interactions, which are known triggers of anxiety in ASD [21,26].

Physiological evidence further supports this trajectory. Autistic children frequently demonstrate atypical autonomic responses during and after exercise, including elevated heart rates, reduced heart-rate variability, and delayed recovery [12,15]. These patterns suggest that PA may impose a disproportionately high internal cost, potentially leading to fatigue, irritability, or dysregulation even when outward motor performance remains strong. Over time, elevated psychophysiological load may reduce motivation, increase avoidance, or negatively affect emotional well-being, outcomes rarely assessed in intervention trials.

The core principle of the Dual-Outcome Model is that motor gains and psychophysiological load represent partially independent developmental phenomena. Improvements in motor competence do not necessarily imply reduced stress or improved regulation. By acknowledging the coexistence of these trajectories, the model offers an explanation for clinical observations in which motor progress is accompanied by distress or disengagement. It further emphasizes the need for multidimensional assessment and individualized intervention design that accounts for sensory thresholds, anxiety profiles, autonomic functioning, and co-occurring conditions such as attention-deficit/hyperactivity disorder or developmental coordination disorder [11], ensuring that PA supports both motor development and overall well-being.

Implications of the model

The Dual-Outcome Model carries several important implications for the design, implementation, and evaluation of PA interventions in autistic children. A central implication concerns the concept of an optimal zone of PA engagement, which proposes that there is a threshold within which activity intensity, sensory input, and emotional demands remain adaptive. When interventions operate within this zone, motor learning is facilitated, participation is sustained, and psychophysiological burden remains manageable. However, when task demands or environmental stimulation exceed an individual child's tolerance, internal load may surpass adaptive capacity, resulting in heightened arousal, emotional dysregulation, or sensory overload. Such responses are well documented in autism research, where excessive stimulation can lead to withdrawal, agitation, or reduced functional engagement [13,18,27]. The model therefore challenges the assumption that increasing activity volume or intensity is inherently beneficial, emphasizing the importance of calibrating PA to avoid maladaptive stress.

A second implication relates to individualized response profiles. ASD is characterized by substantial heterogeneity in sensory sensitivity, anxiety, attentional regulation, and motor competence, resulting in wide variability in psychophysiological responses to PA [11]. Children with co-occurring attention-deficit/hyperactivity disorder may exhibit increased impulsivity and difficulty regulating arousal during demanding tasks, while those with elevated anxiety may be particularly vulnerable to social or performance-related stress [21]. Children with developmental coordination disorder may require greater cognitive and energetic effort to perform motor tasks, increasing internal load despite observable improvements in motor performance. Physiological studies further demonstrate that some autistic children experience disproportionately elevated autonomic strain during exercise, including heightened heart rate responses and delayed recovery [9,12]. These findings underscore the necessity of individualized pacing, environmental modification, and ongoing monitoring rather than reliance on standardized protocols.

A third key implication concerns the decoupling of outcomes. Conventional PA research often assumes that improvements in motor competence, typically assessed using standardized tools such as the BOT-2 or TGMD-2, reflect broader gains in well-being. The Dual-Outcome Model highlights that motor improvements may occur independently of, or alongside, increased stress, fatigue, or anxiety. This phenomenon of masked strain has been noted in clinical observations,

where children demonstrate adequate or improved motor performance during structured sessions yet show dysregulation, avoidance behaviors, or emotional exhaustion afterward [18]. Consequently, exclusive reliance on motor outcomes risks overlooking critical indicators of well-being. Comprehensive evaluation should therefore incorporate measures capturing both motor competence and psychophysiological load to more accurately reflect the full impact of PA interventions.

Operationalization of the Dual-Outcome Model requires parallel measurement of motor competence and psychophysiological load within the same intervention protocols. Motor outcomes may be assessed using standardized instruments such as the BOT-2 or TGMD-2, while psychophysiological load can be indexed through heart-rate variability monitoring, salivary cortisol sampling, adapted perceived exertion scales, sensory response questionnaires, ecological momentary assessment of affect, and post-session fatigue tracking. Longitudinal designs incorporating baseline autonomic profiling and recovery trajectories would allow empirical testing of divergence patterns. Mixed-method approaches combining physiological metrics with caregiver-reported stress or qualitative child experience reports may further enhance ecological validity.

Recommendations for clinicians

Translating the Dual-Outcome Model into clinical practice requires intentional, multidimensional planning and assessment. A critical first step is comprehensive pre-intervention screening to identify factors that may influence a child's psychophysiological response to PA [28-31]. Clinicians should assess sensory processing profiles using standardized instruments such as the Sensory Profile-2, as sensory hypersensitivities strongly predict responses to environmental stimulation [13]. Evaluation of emotional regulation capacity, co-occurring conditions including attention-deficit/hyperactivity disorder, developmental coordination disorder, or anxiety and baseline autonomic indicators such as resting heart-rate variability, when feasible, can help identify children at greater risk of overload [9]. Consideration of fatigue patterns and sleep quality is also important, given their association with dysregulated arousal and behavioral responses during exercise [12].

During PA sessions, clinicians should actively monitor psychophysiological load. Behavioral indicators such as covering ears, withdrawal, pacing, rigidity, or refusal of transitions may signal sensory distress or emotional dysregulation. Observing physiological cues, including heart rate, breathing patterns, or perceived exertion, provides additional insight into internal load. Changes in affect, increased irritability, or escalating resistance across repetitions should prompt timely adjustments to task demands or environmental conditions.

Environmental modification represents another key element of practice. PA settings should minimize unnecessary sensory stimulation by reducing noise, controlling lighting, and maintaining predictable spatial layouts. The use of visual schedules, clear routines, and advance warnings of transitions can further reduce cognitive and emotional load, particularly for children with anxiety or executive functioning difficulties [21].

Task design should be flexible and responsive to individual capacity. Clinicians can modulate demands by breaking activities into smaller steps, avoiding competitive elements when not therapeutically necessary, and incorporating planned sensory or rest breaks. When signs of dysregulation emerge, reducing task complexity or intensity can help maintain engagement while preserving opportunities for motor learning.

Finally, clinicians should adopt a dual-outcome assessment strategy that evaluates both motor competence and psychophysiological load. Motor outcomes may be assessed using standardized tools such as the TGMD-2 or BOT-2, while load can be monitored through heart-rate variability measures, adapted perceived exertion scales, caregiver-reported stress logs, or child self-report when appropriate. This integrated approach ensures that motor improvements are interpreted within the broader context of the child's overall well-being rather than viewed in isolation.

Conclusions

PA interventions consistently produce meaningful motor gains in children with ASD; however, these improvements do not occur in isolation. While motor gains are strongly supported by empirical data, the psychophysiological load pathway is derived from converging indirect evidence and mechanistic inference. Future research must directly test the simultaneous interaction of these trajectories. Converging indirect evidence from neurophysiology, sensory processing research, and studies of comorbid developmental conditions indicates that PA may simultaneously

impose sensory, emotional, and autonomic burdens. These parallel pathways are rarely measured, reported, or acknowledged within the intervention literature, resulting in a predominantly one-dimensional narrative that portrays PA as universally beneficial while obscuring individual variability and potential risk.

The Dual-Outcome Model proposed in this review offers a corrective framework by conceptualizing motor competence and psychophysiological load as partially independent developmental trajectories. Improvements in motor performance do not necessarily imply reduced stress or improved regulation and may coexist with fatigue, anxiety, or avoidance. Recognizing this dissociation is critical for ethical and effective practice.

Clinicians should adopt individualized assessments, monitor indicators of stress, and tailor task and environmental demands to each child's regulatory capacity. Researchers must incorporate multidimensional outcome measures and longitudinal monitoring. Policymakers and program developers should view motor gains as one component of broader well-being. Integrative evaluation appears essential for maximizing benefits while minimizing potential hidden costs, ensuring child-centered PA interventions.

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