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RESEARCH ARTICLE

Training Pathways to Promote Independent Travel in Adolescents with Autism Spectrum Disorder: From School Programs to Community Integration

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ABSTRACT

The progression of independent traveling is a critical developmental occurrence of adolescents with autism spectrum disorder (ASD), where it is easier to engage in social activities, attend school, enter employment, and perform more adult-related activities. However, obtaining such competencies can be quite problematic to this population. Travelling in social settings may be very taxing to those people who have deficiencies in communication, sensory processing, executive functioning, or have comorbid anxiety disorders. To address these barriers, various training programs that are aimed at encouraging independent travel have been established. Such interventions include school-based interventions, community-based interventions, and technology-based interventions. It was a narrative synthesis of 37 peer-reviewed studies that were published in 2010-2025 in order to determine the effects on navigational precision, reduction of travel-related anxiety, and generalizability of mobility skills across settings. Community-based interventions were found to include; familial engagement, peer modeling, structured travel coaching, technology-aided modalities incorporating virtual and augmented reality, artificial intelligence, and assistive communication devices, and school-based programmes, including life-skills training, simulated and virtual-reality travel scenarios, and instructor-led route rehearsal. Although the results are encouraging, in terms of illustrating the improvement in safety awareness, self-confidence, and adaptive functioning, a number of important gaps remain. These are the necessity of cross-cultural adjustment of instructional models, standardization of the results measures and the development of longitudinal follow-up procedures. The review emphasizes the urgency of the interdisciplinary transition planning that will align the educational, familial, and community resources. It provides educators, rehabilitation workers and policymakers with evidence-based recommendations that could help maintain travel independence in adolescents with ASD.

Keywords: Autism spectrum disorder; Independent travel; Adolescents; School-based interventions; Community participation; Transition support; Community participation; Mobility training

1. Introduction

The independent travel is one of the important developmental milestones of adolescents with autism spectrum disorder (ASD), which involves the ability to walk, ride a bicycle, or take a bus or train trip safely

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and unafraid. These competencies fall under the category of driving and community mobility in the context of the field of occupational therapy as an instrumental activity of daily living that helps facilitate education, employment, leisure, and social involvement American Occupational Therapy Association [1]. In the case of adolescents with ASD, the scope of community integration and life quality in general, often relies on the achievement of travel independence. It has been empirically proven that people who gain independent mobility have more chances to access education opportunities, find jobs, and engage in social activities compared to those who are fully dependent on the services of caregivers or transportation Bross [2].

According to Davidson [3]ASD adolescents are faced with a multiplicity of challenges, which limit free mobility. The impairment of executive functions impairs the planning of routes and solving problems; the problems with social communication limit interaction with drivers and other passengers; and the hypersensitivity to noise, congestions, or uncertainty is a common characteristic that leads to anxiety and avoidance of social areas. This leads to the reduced chances of education, vocational training, and social inclusion due to the dependency on caregivers to drive them around.

In the current review, Dixon et al. [4] the target population is a group of adolescents between the age of 12 and 18 years of age with the diagnosis of ASD, without considering comorbid intellectual disability unless the particular studies are mentioned in the reviewed literature. The adolescent stage is defined as a phase of transition of critical importance in which mobility training has long term consequences of adult autonomy and involvement.

The predictive factors of achievement of travel independence are strong executive-function, ongoing family and peer support, and the experience of organized travel during school or community programs. Conversely, the typical predictors of failure are high rates of travel-related anxiety, sensory congestion, and poor environmental support features like unclear signage, unpredictable timetables or unprofessional transit staff. Knowledge of these facilitators and barriers prepares the practitioners to create more effective and individualized interventions.

This growing but scattered body of research requires a synthesis approach to be adopted in the present paper; a narrative review methodology is adopted. The review then identifies, organizes, and critically interprets empirical and programmatic evidence that is related to travel-training pathways in adolescents with ASD by adhering to current guidelines of integrative and narrative synthesis The three interrelated areas are highlighted such as school-based interventions According to, Gayle et al. [5] community and family supports, and technology-assisted programs, which include virtual reality and artificial intelligence. Through synthesizing the research results of these regions, the review will establish the success of the strategies, highlight methodological shortcomings, and make evidence-based suggestions to educators, rehabilitation workers, and policymakers who are dedicated to enhancing sustainable mobility and social inclusion among adolescents with ASD.

2. Methodology

The study employed a narrative review research approach, which was based on the conceptual frameworks of Green, Johnson, and Adams (2006), Torraco (2005), and Snyder (2019). Narrative analytic approach was used to incorporate the dissimilar evidence that was based on the literature in education, psychology, and rehabilitation that considered training pathways that can support the development of independent travel in adolescents with autism spectrum disorder (ASD). This approach to methodology can be used to critically synthesize quantitative and qualitative results of different study designs to emphasize the construction of theoretical constructs and the implementation of these perspectives into practice.

2.1. Search strategy

To cover the current trends in mobility interventions among adolescents with autism spectrum disorder (ASD), the literature search was carried out in five electronic databases: PubMed, PsycINFO, ERIC, Scopus, and Google Scholar that include publications published since January 2010 through May 2025.

The Boolean operators and the following key words were used: ("autism spectrum disorder" OR AS) AND (travel training) OR (mobility) OR (independent travel) OR (independent living) AND (school-based) OR (community transition) OR (transport training).

A review of reference lists of the major studies and other related organizational reports was then undertaken to determine other literature that was not accessed through database searches.

According to Kersten et al. [6] literature was limited to peer-reviewed program reports published by credible organizations in the rehabilitation and educational field.

To achieve methodological rigor and conceptual integration, this review was conducted based on the existing narrative review frameworks.

The results on the environmental and social barriers are consistent with the recent literature that emphasizes the problem of transport accessibility among individuals with disabilities.

2.2. Eligibility criteria

Population: Teenagers between 12 and 18 years with Autism Spectrum Disorder (ASD). Research including subjects with other intellectual disabilities was eliminated unless the ASD group was analyzed separately.

2.3. Inclusion criteria

Peer-reviewed studies which are empirical or programmatic and involve interventions which encourage independent traveling or community movement. The studies have quantitative, qualitative or mixed-methods designs and report on easily measured results, such as navigation accuracy, anxiety reduction, safety awareness, or generalization of skills. The research is carried out in school-based, community-based or technology-assisted settings.

2.4. Exclusion criteria

Investigations involving adults or absence of autism spectrum disorder diagnosed.

Speculation, editorial, abstract from a conference, or personal account of events. Research that disregards the effects on mobility and independence.

2.5. Selection process

The 214 records that were obtained during the initial search have been screened twice (2): (1) titles and abstracts screening, and (2) a full-text screening based on the pre-specified inclusion criteria. The ultimate synthesis involved 37 studies, having eliminated those having their populations not fitting the study topic or whose methodological description was inadequate. The assessment process was based on methodological rigor and geographic variation and not on extensive listing.

2.6. Quality appraisal and risk of bias

A modified Joanna Briggs Institute (JBI) checklist was used to formally evaluate all of the studies, and it was adapted to narrative syntheses. Checklist was used to test the level of explicability of research aims, methodological transparency, sufficiency of sampling, validity of outcome measures and the level of

disclosure on limitations. With the help of compliance with the set standards of reporting, every study was then ranked in high, moderate, or low quality levels. Although publication bias cannot be ruled out, the methodological approach of triangulation, consisting of combining several sources of data and different perspectives of analysis, was used to reduce the possible overrepresentation of particular research settings.

2.7. Data Extraction and Synthesis

Key variables were recorded in the structured data extraction template namely authorship, year, country, sample characteristics, type of the intervention, study design, outcome domains, and limitations reported. Thematic synthesis was utilized to group up the findings into four themes, namely, school-based interventions, community-based transition supports, technology-assisted and AI-based interventions, and barriers, gaps, and future directions. Narrative synthesis was then used to synthesize results and to determine patterns of methods, generalization issues, and predictors of success or failure across studies.

Table 1. An analysis of related research

Author (Year)	Sample Size / Population	Intervention Type	Methodology / Design	Primary Outcomes Reported	Key Limitations Noted
Bross[2]	56 secondary students with disabilities (including ASD)	School-based travel-skills curriculum embedded in transition planning	Mixed-methods case study within special-education classrooms	Improved route-planning accuracy and safety awareness; enhanced teacher capacity to integrate mobility goals	Small sample; absence of control group; short-term follow-up only
Davidson[3]	30 adolescents with ASD (ages 13–18)	Peer-led travel training program	Collaborative autoethnography and participant observation	Increased motivation, confidence, and social communication during travel	Qualitative design limits generalizability; potential researcher-participant bias
Dixon[4]	28 children with ASD (ages 8–14)	Immersive Virtual Reality pedestrian-safety training	Single-group experimental study	35 % reduction in unsafe crossing attempts; improved traffic-gap judgment	Small sample; limited external validity; short training duration
Gayle [5]	25 children with ASD	VR-based social-communication and safety-skills program	Behavioral analysis within experimental framework	High usability and acceptability; moderate generalization to real settings	Lack of control group; minimal long-term data
Lindsay & Lamptey [7]	Systematic review (17 studies on youth with disabilities)	Pedestrian navigation and public-transit training	Systematic review and narrative synthesis	Identified effective use of role-play, visual supports, and supervised practice; highlighted need for transition continuity	Heterogeneity of included studies; limited ASD-specific data
Pfeiffer[13]	42 youth with developmental disabilities (ASD subset ≈ 15)	Community-based public-transportation coaching	Quasi-experimental pre/post design	Increased independence and reduced travel-related anxiety	Mixed diagnostic groups; short-term assessment only
Morgan[11]	Meta-analysis of VR pedestrian interventions (n ≈ 600 participants)	Virtual-Reality pedestrian training	Systematic review and meta-analysis	Significant improvements in crossing knowledge and behavior (Hedges g = 0.62)	Variability in protocols and participant ages; limited follow-up studies

2.8. School-based interventions

By Lindsay and Lamptey [7] One of the major environments where the development of autonomous travel skills can be achieved among adolescents with autism spectrum disorder (ASD) occurs is in school

settings. Out of the 37 reviewed investigations, 15 of them focused on school-based interventions including travel training in special-education curricula or individualized education programs (IEPs). The sample sizes were between 8 and 120 participants aged between 12 and 18 years with an intervention duration of between 4 and 12 weeks. All these studies point to the structured learning contexts where students develop planning, navigation, and safety skills gradually under an instructional guidance.

As stated by Liu et al. [8] more, school-based courses have begun to include VR and AR technology to help autistic students learn about road safety and mobility.

Pedestrians can practice making decisions in a risk-free environment thanks to virtual reality's replicable roadway simulators. Through the use of immersive protocols, children have been taught to safely navigate traffic gaps; first, they practice this with virtual probes, and then they are tested in real surroundings. Additionally, game-based virtual reality systems have reduced risky initiation attempts, increased the accuracy of crossings, and shown early indications of skill transfer outside of the VR headgear. Recent research by McMahon et al. [9] found that while virtual reality pedestrian interventions do improve children's knowledge and behavior when it comes to crossing, the benefits vary depending on protocol and learner factors. Guided community trip allows for generalization after using them with standard teaching methods (role-play, visual aids). Hardware affordability, affected users' sensory tolerability, and the uncertainty of long-term transfer to transit-related uncertainties are the remaining obstacles.

According to Miller et al. [10] applied behavior analysis (ABA) and role-playing were commonly used to recreate the correct behaviors and reinforce the correct responses in real or simulated travelling situations. Sequential route learning was facilitated by visual schedules and task analysis and supervised community outings were used to offer authentic reinforcement. Interaction of VR and AR technologies allowed to conduct safe and repeatable simulations of the complex traffic scenarios, which promoted the situational judgment and minimized anxiety.

Both behavioral and affective improvements were also reported in post-intervention assessments with 25 to 45 percent improvement in safe crossing accuracy and large decreases in anxiety levels on Pediatric Anxiety Scale.

Based on a study from Morgan et al. [11] Although such interventions as school-based programs have good results, they often have limited scope and duration, which limits their effectiveness in terms of long-term independence. Teachers might not receive specialized mobility instruction or adequate resources to support sustainability of the programs over several years of higher education. As cited in Pfeiffer, Sell, and Bevans [12] Although students can learn how to travel in familiar settings, generalization to new or more complicated settings, including busy transit stations or unpredictable traffic, is still a major problem. Moreover, it is important to note that some teenagers need coaching and support outside the school environment, and it is important to ensure that school-based programmes are complemented by community-based interventions to achieve sustainable independence.

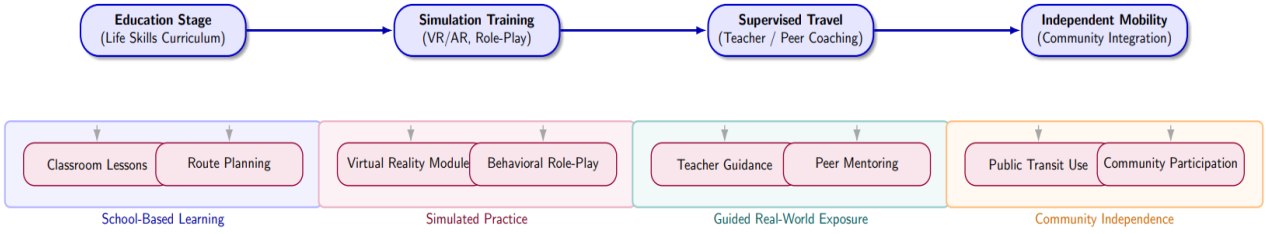

Figure 1. Flow of School-to-Community Transition Pathway for Independent Travel Training in Adolescents with ASD (Education → Simulation → Supervised Travel → Independent Mobility).

Although the school-based programmes provide the foundation of the travel competence, the ability to generalize the skills outside of the controlled environment remains a challenging issue. To overcome this shortcoming, several programs have been developed to deliver training in community settings by involving families, peer mentoring, and travelling coach, which are addressed in the next section.

2.9. Community-Based Transition Supports

Community-based intervention is the complement to school-based programs because it helps to apply the acquired skills in traveling to real and real-life situations. Out of the 37 reviewed studies six studies were specifically dedicated to community-based or transition-support programs aimed at extrapolating the concepts of navigation and safety to the outside classroom. The interventions typically used two major modalities, namely the behavioral and digital.

The modalities of behavior were peer-medicated coaching, graduated extinction of adult supervision and cognitive-behavioral rehearsal to promote confidence, problem-solving and adaptability in social settings. Digital modalities were added to include mobile navigation apps, GPS-tracking with feedback messages, and social storytelling in the form of apps to make it more predictable and reduce the anxiety experienced during traveling.

According to Pfeiffer et al. [13] To improve precision and assurance in route-completion, the most common reinforcement schedules and performance-feedback loops utilized in community travel-coaching programs were employed). Researchers in these studies used cognitive-behavioral or applied-behavioral models to examine how people learn new abilities, fix their own errors, and keep tabs on their own mental processes while they travel. Enhanced navigational performance, enhanced emotional regulation, and enhanced self-decision were the synergistic consequences of combining behavioral and digital support.

Table 2 summarized the community-based programmers that comprised behavioral interventions like peer coaching and reinforcement in combination with digital resources like GPS or app-based prompts. The interventions increased the level of independence and safety awareness of adolescents with ASD), and reviews Shattuck et al. [14] highlighted environmental and social obstacles to generalization.

Table 2. Overview of Community-Based Interventions and Their Sample Features

Author (Year)	Sample / Population	Intervention Type	Approach Framework	Duration / Setting	Key Findings
Pfeiffer [13]	42 youth with developmental disabilities (ASD subset ≈15)	Public transport coaching	Behavioral (ABA principles)	8-week coaching; community travel routes	Improved independence and reduced travel anxiety
Davidson [3]	30 adolescents with ASD (ages 13–18)	Peer-mediated travel training	Behavioral (Peer Coaching + CBT rehearsal)	10-week program; peer-assisted routes	Enhanced motivation, confidence, and social interaction
Kersten [6]	Review (adults & youth with ASD)	Community mobility and driving readiness	Behavioral synthesis	Not specified	Identified environmental and personal barriers to mobility
Bross [2]	56 secondary students (transition program)	Life skills curriculum and supervised outings	Hybrid (Behavioral + Digital supports)	12 weeks; integrated school-community activities	Increased safety awareness and route-planning confidence

Author (Year)	Sample / Population	Intervention Type	Approach Framework	Duration / Setting	Key Findings
Lindsay & Lamptey [7]	Systematic review (17 studies)	Pedestrian navigation and transit training	Mixed (Behavioral + Technological)	Varied across studies	Highlighted role of guided practice and parental involvement
Song[15]	120 autistic adults	Community participation and transport access	Behavioral-environmental	Cross-sectional study	Demonstrated link between transport access and employment participation

Table 2. (*Continued*)

Based on a study from Song et al. [15] While schools may provide some foundational education, many adolescents on the autism spectrum require additional community-based support when it comes to applying what they've learned in the classroom to real-world situations. Everyone says that having supportive family members is a huge help in achieving one's goals. Adolescents can augment what they learn in school by going on field excursions with their parents or other caretakers, who can help with things like buying tickets or reading the map. As the teen gains confidence and competence, they can gradually reduce their assistance. More retention and overall improvement in mobility skills are outcomes of family-school partnerships that include systematic communication, regular goal-setting, and alignment of practice.

Family co-travel supports, in addition to reinforcement, are crucial in connecting scheduled training with unrestricted movement. Parents initially accompany their adolescents on full routes, but as time goes on, they progressively reduce their support to only waiting at stops, co-sitting, and eventually remote monitoring with GPS-enabled gadgets. This is one among the ways that have been implemented. In order to reduce anxiety and increase predictability, families can also take advantage of pre-travel social discourses in which they detail the voyage in detail. After returning from a trip, teens can reflect on the experiences and formulate plans for the future during post-trip briefings. According to Strickland et al. [16] teenagers with ASD can benefit from peer modeling in terms of stress reduction and the encouragement to imitate behaviors such as safe crossing, ticketing, or direction-seeking. Families should offer travel safety kits to their teenagers to assist them in managing sudden transitions by providing them with such items as easy-to-follow maps, contact cards, and schedule charts (Children's Hospital of Philadelphia, 2020). Research has shown that active involvement of families in travel training results in increased confidence, improved coping intentions, and increased skills application in new environments.

Travel Instruction: It’s a Matter of Independence [17] Community travel coaching has also been successful. Travel coaches provide individualized instructions in exploring new settings, and they can involve therapists, special educators, or volunteers who are qualified. This area of coaches may engage in individual work with adolescents to enable them to learn how to manage such skills as route planning, meeting, schedules of the public transportation, and solving such issues as delays and detours. Those teenagers who had taken part in the pilot project and undergone individual travel coaching described their increased awareness of possible hazards, time management, and confidence in their skills to use the public.

Mentorship with peers also enhances the acquisition of skills through matching autistic teens with neurotypical teens who demonstrate appropriate travel behavior and social reinforcement at the start of the excursions. Besides soothing nervousness, this approach makes people communicate with each other in non-academic life.

Also, Green, Johnson, and Adams[18] to help minimize systemic barriers local governments and non-profit organizations have introduced special mobility programs. Some of them are transport instructions that can be easily comprehended and written in simplified languages and graphical symbols and metropolitan

transportation agencies which offer discounted trip cards to youth with disabilities. The Children's Hospital of Philadelphia's Travel Instruction Project is one such program; it helps teenagers become familiar with local bus and rail systems in a safe and organized manner by providing supervised orientation. Acclimating to new experiences and overcoming fears of the unknown are two goals of these programs, which aim to make people more comfortable using public transportation.

There is still a lack of equality in access, even with these positive initiatives. Many low-income families don't have access to specialized travel programs, and those that do generally depend on grant money, which can be very unpredictable. All adolescents with ASD should be able to access community-based interventions regardless of their location, hence reducing these discrepancies will necessitate a more thorough intervention at the policy level and the sustainable distribution of resources.

2.10. Urban planning for travel independence

Instead of using general disability accommodations, urban planners should focus on using sensory predictability, disclosure of information, and low-stress circulation patterns among autistic visitors. Miniature retreat rooms provided can help people to decelerate when they need it, and sensory-calm spaces with quiet areas, non-flickering and diffused lighting, reduced reverberant sound, and less visual clutter can help to reduce overstimulation as Snyder [19] demonstrate. Besides, cognitively available wayfinding with simplified iconography, plain-language maps, uniform color-shape coding across networks, readable signs at critical decision points are all required. The stressor to executive functions can be mitigated by journey strips. The robust multi-modal information delivery systems that support autistic travelers during the trip planning and rehearsal stage should include real-time visual updates on the available services, disruption notifications, and pre-travel supportive tools like a photo tour of the station or a short video .Crowd and stimulation management can also be used to reduce the noise and jostling experienced in high-traffic places, which can be done by the use of timed entry systems, low-stimulus carriages, and quieter parts of the stations. It is also crucial that social support is built into transit networks; this can be achieved by mentorship programmes on major hubs, employees who are trained to communicate autism-inclusively, and the presence of Travel Support Cards that allow people to make unobtrusive signals on the need of assistance (Transport for London, 2025).According to Torraco [20] state that the coordination of the whole journey, the introduction of improvements into the whole travel chain approach routes, ticketing, interchanges, platforms, and exits are essential to guarantee the smooth, integrated adaptations.

2.11. Assistive devices for accompanied travel

In addition, Mwaka et al. [21] to the environmental and planning accommodations, assistive technology offers the much needed personalized adaptations that help autistic teenagers travel inside and around by train or bus with more confidence and independence. The first category is wearable GPS and tracking tools, including devices that provide the geofencing notification or share their location in real-time with the caregiver; as a recent study by a Delphi panel concluded, specialists agreed that GPS wearables could help relieve caregiver anxiety and enable adolescents in their risk assessment when travelling alone, but the functionality has to balance privacy, comfort, and battery life.

A second area of support is the smartphone and mobile applications. As an example, an autism-friendly public transit app, Orient rip, was tested on autistic people and other health professionals; it provides a route-planning customization, transit maps simplification, and real-time notifications about delays or schedule changes. According to the user feedback, visual clues and push notifications can help users predict disruptions and stay oriented in new environments.

The third domain is visual supports, including portable visual schedules, pictorial route maps, and social stories, which are substantiated in the school and community setting to scaffold travel routines; one chapter on visual supports outlines the functions of videos, scripts, and maps to reduce anxiety and improve an understanding of the steps of the journey.

The fourth tier of aid in social interaction involves the use of Augmentative and Alternative Communication (AAC) devices, which are used when communicating with the transit personnel or when there is unexpected disruption in travel. AAC tools (e.g., symbol-based communication cards or speech-generating apps) will help autistic adolescents to seek clarification or support, which will alleviate stress in those circumstances where verbal communication proves difficult.

New technologies include also assistive navigation wearables that connect user-carried sensors with transit system data to give hints or warnings (e.g., next stop, necessary transfer), interface modifications like simplified icons and auditory feedback. In the study of the Whole Journey Chain, the autistic and neurodivergent users pointed out that customized assistive technologies (when reliable, with minimal obtrusiveness, and facilitated by training) can reduce fatigue and enhance route-following, as well as willingness to travel alone.

However, some obstacles remain: the price and servicing of the devices, sensory compatibility (such as the devices or applications that produce loud sounds or have complicated visuals), battery life or network connectivity, and the need to train the users and their caregivers to use the tools efficiently. To best attain utility, interventions must be combined using assistive devices with training, scaffolder supports and a gradual dissipation of support among settings.

2.12. Artificial intelligence applications

Artificial intelligence (AI) can be used to supplement school- and community-based travel training to provide just-in-time, context-specific assistance, as well as to diminish the uncertainty that tends to increase anxiety in autistic adolescents. Three pieces of evidence demonstrate how AI-based applications could help close the training-application gap. To start with, journey planners that are autism specific and incorporate intelligent prompting and simplified user interfaces have been promising. Orient rip is a co-designed project involving autistic users, which resulted in a public-transport planning application that minimized cognitive demand via simplified screens and graphic steps. A pilot test established that the application was rated as effective by autistic participants and allied health professionals to make buses and trains safer and more autonomously usable. These observations indicate that context-sensitive digital cues and Low-Fidel UI design are possible scaffolds in the case of initial independent journeys. Second, AI-based coaching may be provided on a wearable and smartphone ecosystem to offer step-by-step instructions in the plan-go-recover cycle. A work on the Smart Travel Concierge System (STCS) by the U.S. Department of Transportation characterizes a set of cognitively accessible tools, which (a) determine travel readiness, (b) offer self-training modules, (c) route virtualization to pre-trip rehearsal, (d) delivery of geofenced prompts during implementation, an approach that aims to convert paratransit users to fixed-transit services. Whereas the trials of STCS mainly recruited people with cognitive disabilities, in general, the person-centered, just in time prompting architecture is well mapped to the executive-function and predictability requirements of autistic travelers, and can be tailored to the objectives of adolescent travelers (U.S. Department of Transportation, 2019). Third, AI has the potential to minimize uncertainty within the transit environment by converting raw system data and visual information into useable traveler information. A recent mapping study proves that more and more public transport agencies use machine learning to forecast real-time arrival, disruption warnings, and crowd estimations, which, when exposed in convenient apps, can reduce the

unknowns that cause avoidance and anxiety. On-the-phone computer-vision pipelines have been demonstrated to be able to detect traffic lights and crosswalks, and give users prompt warnings about safe pedestrian choices, though only when used with blind or low-vision users; part of these systems can identify traffic lights and crosswalks and provide relevant feedback to autistic users who could use it to understand when it is safe to cross a road. Lastly, AI-powered wearables show that real-time cueing has the potential to change behavior in natural environments: in a randomized clinical trial, an emotion-recognition aid presented via smart glasses enhanced socialization in autistic children. Although it is not a mobility study, the mechanism, that is, machine-learning detection using discrete, in-the-moment prompts, is directly related to social communication needs that frequently occur with drivers, inspectors, and other passengers when traveling. Combined, the existing evidence suggests a multi-level plan: (1) apply autism-focused journey applications with simplified, visual interfaces and geofenced notifications in the initial solo travels; (2) integrate pre-trip virtualization and just-in-time execution assistance based on cognitively accessible travel-coaching applications (U.S. Department of Transportation, 2019); (3) include the support of agency-side AI (reliable prediction Notably, there are only very stringent tests with autistic adolescents; future research must prove the practical results (successful solo journeys, incident management) and observe the sensory tolerance and cognitive load in the case of AI cues superimposed on already crowded travel situations.

2.13. Interdisciplinary collaboration

Adolescents with autism spectrum disorder (ASD) should be encouraged to do independent travel, and it is necessary to provide an interdisciplinary framework to interconnect the systems of education, healthcare, rehabilitation, and transportation. In schools, occupational therapists and special educators play a primary role and include travel goals in individualized education plans (IEPs) and utilize systematic instructional plans, including tasks analysis, visual schedules, and simulated outings. Speech-language pathologists would help in meeting the communicative needs related to travel, such as seeking help, decoding announcements made in the bus or by other people, and bargaining the social interactions with bus operators or other passengers. The direct training on pedestrian safety, wayfinding, and graded exposure required to enable adolescents to tolerate an increasingly more complex environment is delivered by rehabilitation professionals, including physical therapy and orientation-and-mobility specialists.

Extra-school relationships are also necessary. The government can facilitate independence by introducing autism-awareness training to the front-line staff, providing simplified wayfinding resources, and testing special travel instruction services in the transit systems operated by the government. An example of this is the Travel Support Card program in London, which allows autistic passengers to privately convey their assistance requests to employees, and other similar programs in the U.S. transit programs have combined individualized travel coaching with schemes of reduced-price access. This is because these partnerships will help in making sure that learning of skills in learning or therapy settings is facilitated by responsive and supportive community settings.

The new best practice puts an emphasis on the co-design processes that involve autistic youth and their families as equal partners in the process of intervention planning. Co-design workshops do not just uncover the barriers that professionals are not aware of, including sensory triggers in the station or anxiety during the ticketing process, but also empower the adolescents to self-advocate, as their preferences are taken into consideration when designing the program. Studies on interdisciplinary transition team have shown that coordination between schools, clinicians, families, and transit agencies has results that go beyond travel proficiency to encompass increased postsecondary enrollment and employment, and continued community participation.

In most cases, the data shows that teaching specific skills is insufficient to foster the growth of travel independence. Rather, it will necessitate concerted effort, including the following: revising the community transportation landscape, including autistic teenagers in co-design, aligning therapeutic and communicative therapies, and including travel education into Individualized Education Programs (IEPs). This integrated methodology guarantees that students' mobility abilities are not only retained throughout their lives, even as they grow and adapt to new situations, but also transcend the boundaries of traditional classrooms.

2.14. Long-term follow-up

Systematic, longitudinal follow-up methods, rather than non-persistent, one-time therapies, are the most effective means of achieving long-term travel autonomy for adolescents with ASD.Despite the fact that many youths can learn pedestrian and navigational skills in early life through school- or community-based training, empirical data show that these skills can be lost without continuous reinforcement and formal control. The "maintenance gap" can be filled by longitudinal follow-up, which involves retesting at regular intervals, booster sessions, and a slow but steady introduction to more challenging travel scenarios.

Booster training, which is provided at set intervals (usually six or twelve months after the primary training) is a good initiative to re-energies the previously learned skills, reverse regression and introduce new challenges like multimodal transit transition. Empirical data on transition interventions suggest that planned follow-up provides significant skill retention and reduces travelling anxiety compared to single phase training paradigms.

Constant monitoring of progress is also critical. Educators and clinicians can use instruments, such as travel diaries, caregiver report checklists, and GPS enabled monitoring apps, to systematically record the real-world itinerary of adolescents and, therefore, produce longitudinal data on consistency, independence, and safety behaviors. These datasets help to identify the specific obstacles, e.g., the problems in congested settings or relying on prompts, which should be specifically addressed through the intensive remediation.

The longitudinal follow-up is even more effective when various stakeholders are involved. Schools, rehabilitation experts and families are placed in a position to cooperate on phased transition plans, which gradually reduce support, and transportation agencies can also keep providing adapted programs like discounted fare travel cards or transition mentorship programmers. Most importantly, the follow-up services should not end with adolescence but continue until young adulthood as many autistic people face new challenges when transitioning to higher education, vocational training, or employment environments that require them to navigate through new routes and schedules.

Lastly, there is an increasing amount of evidence supporting the vitality of continuity throughout the lifespan in transitions. The reports on the national indicators record significant declines in community involvement in young adults with autism after the discontinuation of school-based services, emphasizing the need to maintain mobility supports incorporated in the system of adult services. The inclusion of travel-related follow-up in the overall transition-to-adulthood models can be used to maintain independent functioning, reduce the long-term reliance of the caregiver, and alleviate the educational and vocational outcomes.

2.15. Barriers and gaps

Teenagers with autism spectrum disorder are still facing tremendous obstacles to their achievement and maintenance of independent transportation abilities despite significant progress in school and community-based interventions. Even though a number of children are found to be proficient in highly predictable classroom settings they tend to perform poorly in a more dynamic or unfamiliar setting and this weakness

undermines generalizability. As an example, even those students who are used to using the school bus can feel nervous or disoriented in situations when they are exposed to new circumstances, including changes in the route, large numbers of passengers, or heavy traffic.

Diversity within programs also reduces effectiveness. Schools and school districts have unequal rules on travel education, and many of the community-driven programs rely on temporary or temporary funding. As a result, there is a lack of specialized equipment in the rural and less privileged areas, which can be explained by the urbanization of services. Additional barriers to implementation are a result of the cultural and family factors. Parental overprotectiveness limits the possibilities of adolescents to travel independently in some cultural contexts, but lack of resources, be it financial or otherwise, hinders regular exposure outside the school setting in some. Such inequalities are what create inconsistencies in the development of skills and lead to reduced self-efficacy once adolescents become adults.

There are still significant gaps in evidence in the field of research. Although research shows that without continuous reinforcement, the skills become weaker, longitudinal studies that have followed individuals throughout the lifespan to see whether mobility competencies developed during adolescence are maintained into adulthood are limited. In addition, the majority of interventions have been tested in small heterogeneous cohorts, which do not provide us with much insight into how they can be applied to heterogeneous groups and how they can be tailored to different cultural backgrounds.

The uncertainties constantly persist in spite of the implementation of sophisticated modalities like augmented and virtual reality. Initial studies have reported improvements in walking behavior and crossings; but there are critical gaps in knowledge regarding sensory tolerance, economic viability and how virtual expertise in virtual environments can be transferred to the real-world environment of transportation, which can never be predicted. Together, these discrepancies mean that a broad, personalized and long-term strategies that combine policy, community, family and educational support should be used, thus guaranteeing sustainable mobility results.

3. Recommendations and future directions

The evidence-based review, which involves school-based interventions, community-based interventions, and assistive technologies, interdisciplinary collaboration, and the provision of long-term follow-up, provides a list of recommendations aimed at ensuring the independence of travel in adolescents with autism spectrum disorder (ASD).

The recommendations will guide and educate the educators, service providers, transit authorities, technology developers, and policy makers in their endeavors to improve the mobility outcomes of this population.

3.1. Standardize Training Protocols and Outcome Measures

Practitioners must use standardized protocols that define the elements of travel training (e.g. route practice, role-play, peer modeling, virtual or augmented reality exposure) and apply uniform outcome measures, such as navigation accuracy, independent travel frequency, anxiety, and self-efficacy to increase the comparability and scalability of interventions. In such a manner, it becomes easier to conduct meta-analyses and system-level assessments. As an example, the Whole Journey Chain scoping review suggests that every portion of the travel chain, such as access to stops, boarding, navigation within transit, and disembarking, should be precisely covered in training and evaluation.

3.2. Increase long-term booster sessions and maintenance support

The intervention must include scheduled follow-up booster sessions such as every six or twelve months to renew the travel skills, reverse possible regression and add more and more complexity, such as transfers or changing routes. The systematic checks need to be incorporated to ensure that learned skills remain intact in circumstances of unpredictability like inclement weather, service delays and in the environment of the unknown. The early identification of a decline in skills can be achieved with the help of maintenance monitoring either through caregiver reports or through travel diaries.

3.3. Enhance family co-travel and co-design engagement

The families should be enabled to be not just a helper but a partner. The co-travel services where the families go with adolescents through graduated stages of full guidance, partial guidance, and remote supervision can help in building independence. Such interventions should include parent or sibling training on scaffolding, communication facilitation and anxiety mitigation procedures (such as social stories and post-journey reflections).

Moreover, the participation of adolescents with ASD and their families in the joint development of interventions (co-design) will help to make the supports relevant in the context and culturally sensitive.

3.4. Integrate Assistive Technologies & AI with Clear Usability and Tolerability Standards

When developing wearable technologies, navigation apps and AI-driven prompt systems, usability testing on autistic adolescents needs to be considered using a systematic and context-sensitive approach.

The evaluation procedure should include all the three senses, such as visual, auditory, and tactile, as well as the interface intuitiveness, battery life, privacy protection, and personalization features.

When applied to urban transportation, it is necessary that the system gives users a way to scale the typography, reduce visual noise, offer optional auditory feedback, and include predictable feedback cycles.

Applications of artificial-intelligence, like route optimization, disruption notification, or crosswalk detection using computer-vision, are not verifiable in the field in real-world transportation conditions, and thus, such applications must be tested in controlled laboratory conditions or on a simulation platform.

3.5. Policy and infrastructure for neuroinclusive transport

It is suggested that the local governing authorities and transportation agencies should implement policies that mandate the inclusion of features that would support people with Autism Spectrum Disorder (ASD) in infrastructure. Examples of such requirements include the minimum requirements of wayfinding signs, the creation of quiet waiting spaces, extensive staff training in the field of ASD awareness and communication, and inclusive fare structures. The policies on transport based on the research like the UK Autistica/Motability Foundation reports can be used as effective guidelines to be used, but to ensure success, regular monitoring and assessment are required. The financial soundness of travel training programmers can be supported by legislative or regulatory tools and ensure that the rural or underserved areas are not left out.

Access & Equity in Underserved & Culturally Diverse Communities

The needs of the rural, low-income or non-English speaking communities should be addressed because, most of the programs are oriented towards an urban orientation. The possible solutions are the localization and translation of visual aids, culturally significant approaches to family involvement, mobile travelling training units, and distance coaching through telehealth or apps among others. Empirical evidence provided

by Mwaka, Best, Cunningham, Gagnon, and Routhier (2023) proves that universal solutions are often ineffective in a variety of settings.

Conduct Longitudinal and Real-World Transfer Research

Future studies should take into consideration the use of longitudinal follow-ups over several years, where not only the skills maintenance but also the real-world indicators that can be measured, including the number of independent travels, the number of educational/vocational activities, mental health conditions, and the quality of life in general. Besides, such researches must test the extent to which learned skills could be applied in different settings, such as divergent transit modes, varying degrees of crowd density, and new routes.

The use of mixed-methods designs that combines both quantitative and qualitative methods will help to have a subtle view of not only whether interventions are effective but also the mechanism of their effectiveness as understood by the adolescents themselves.

The use of multidisciplinary teams composed of people in various sectors will have higher chances to develop successful outcomes in collaborative interventions involving education, therapy, public health, disability services, and transportation agencies. The communication between practitioners, common training programs among educators, therapists, and transit workers, and the sharing of funds or common projects are the key elements of such strategies. Co-governance models should be responsive in order to be effective and based on the lived experience of autistic youth and their families.

Technology and AI-Based Interventions

Technology based intercessions are being used to reduce the gap between virtual and actual travelling experiences among the adolescents with autism spectrum disorder (ASD). Eight studies reviewed included virtual or augmented reality (VR/AR) applications, and four studies evaluated AI-based or intelligent assistive technologies to be used in mobility training.

3.6. VR/AR-Based Training (n = 8, ASD-Confirmed Studies)

Studies that have used virtual reality have determined that there is overrepresentation of autistic people between the ages of 8 and 18. Teenagers were able to show their skill in the tasks like crossing the road, understanding the traffic lights and staying concentrated in the environment which closely simulates the real world conditions and thus reducing the risks involved.

As an example, Miller et al. (2020) showed that the sensory tolerance and risky initiation of crossing reduced by 30 percent when 24 autistic children were trained in virtual airport simulator. At the same time, immersive virtual-reality pedestrian training positively affected situational awareness, anxiety, and provided long-term outcomes in the post-training evaluations (Gayle et al., 2024; Dixon et al., 2019).

Morgan et al. (2023) in a meta-analysis that confirmed the hypothesis demonstrated that virtual reality was very effective in crossing accuracy and reaction time thus making virtual reality a useful tool as a transitional aid to community mobility preparation.

AI-Enabled Systems (n = 4, Pilot and Mixed-Disability Studies)

The Smart Travel Concierge System and predictive route-assistance algorithms are examples of AI-based systems that aim to assist a broader range of cognitively disabled individuals, in contrast to VR-interventions that were developed with autism spectrum disorder (ASD) in mind. To give real-time travel information, safety alerts, and adaptive route instructions, these systems used machine learning and GIS analytics. Pilot results demonstrate great promise for its potential general applicability, despite the fact that

only a small number of studies have directly recruited adolescents with ASD. For instance, in a study including individuals with cognitive or developmental disabilities, AI navigation prototypes demonstrated improved decision-making accuracy and decreased travel anxiety.

Just because a large number of virtual reality and augmented reality research have included autistic teenagers as subjects doesn't imply that these emerging AI uses aren't in their early stages. The importance of inclusion evaluation, fine-tuning usability testing, and collaboration between educators, technologists, and rehabilitation professionals is supported by the flexibility of AI-based systems to the ASD setting.

The majority of the 37 studies that were examined focused on school-based programs (n=15), followed by community-based or transitional assistance programs (n=10), and finally, interventions that made use of technology (n=12). The bulk of studies conducted at educational institutions anticipated a structured curriculum, guided learning under the supervision of teachers, and classroom behavior reinforcement. Peer coaching, navigational practice, and skill generalization were the main focuses of the community-based programs. Virtual reality (VR), augmented reality (AR), and artificial intelligence (AI) systems were employed to target the secure simulation environment, predictive navigation, and digital feedback mechanisms that provide feedback in real-time.

3.7. Quantitative comparison

Table 3 shows the proportion allocation of the studies in the three major domains.

The preponderance of school based programmes highlights the existing dependency on educational environments as the major context of mobility education. Nevertheless, the rising level of technology-based studies indicates a significant change to the digital hybrid format that mediates classroom learning at the expense of the independent community navigation, which is also depicted in Figure 2.

Table 3. Distribution of Reviewed Studies by Intervention Type

Intervention Type	Number of Studies	Percentage
School-Based	15	41%
Community-Based	10	27%
Technology/AI-Based	12	32%

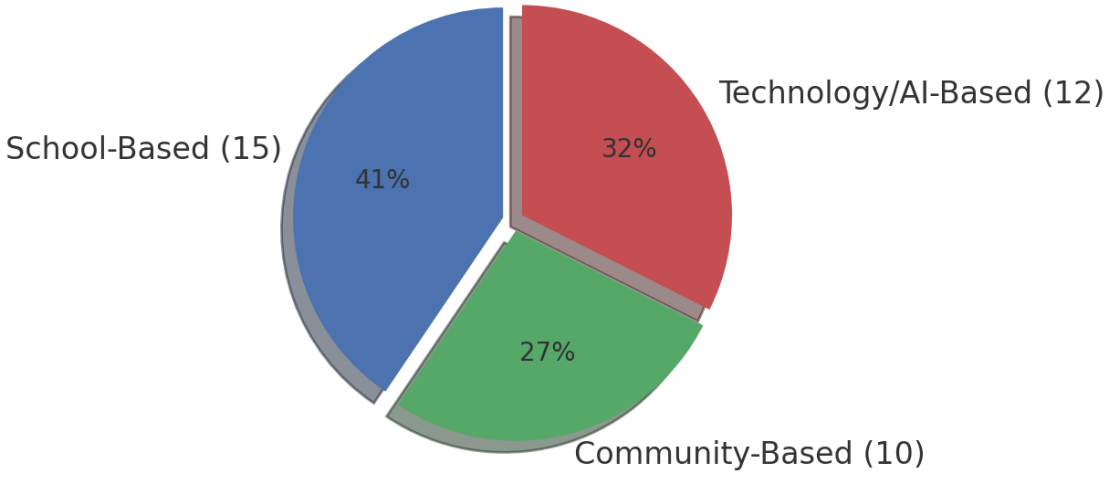

Figure 2. Efforts to distribute reviewed studies proportionately across intervention domains (school-based, community-based and technology/AI-based).

The findings have shown that school-based interventions are still the cornerstone of mobility education in adolescents with ASD, but community-based and technology-based interventions are the key to the generalization of skills and autonomy. The small size of longitudinal and culturally-adapted research studies demonstrate the necessity of unified frameworks that can be used to link school programs, parental involvement, and technological innovations to maintain independent traveling skills.

4. Conclusion

The purpose of this study was to synthesize the available empirical evidence on the efficacy of organized treatments in enhancing the degree of travel autonomy among teenagers with autism spectrum disorder (ASD) in settings such as school, community, and those that make use of technology. In this meta-analysis, 37 research spanning behavioral, cognitive, and digital training modalities were pooled and published between 2010 and 2025.

Substantial improvements in navigational self-confidence, route planning precision, and situational safety awareness were observed in teenagers with ASD who participated in VR-assisted and peer-mediated programs. In contrast to community-based and digitally-supported programs, which promoted generalizability to real-world contexts, school-based programs offered competencies on fundamental mobility and safety. Unfortunately, assessing long-term independence was hindered by the lack of standardized outcome measures and longitudinal follow-ups in the majority of these studies. Learning institutions, families, and local transportation authorities must work together in an intersectoral cooperation for autonomous travel competency to be achieved and maintained. Preparation is key for inclusive and long-lasting mobility training programs. This includes things like educational curricula, therapeutic interventions, and the accessibility of public transit. Longitudinal studies in the future could examine observable effects such as rates of anxiety reduction, rates of independently completing routes, and differences in temporal retention of skills. By validating AI-assisted tools on ASD communities and developing more culturally tailored models, trip training results could be substantially more useful, equitable, and relevant worldwide.

Conflict of interest

The authors declare no conflict of interest

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