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Virtual reality for real world safety: Evidence from a quasi-experimental study with deaf children

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Abstract

This study examined the effectiveness of a virtual reality (VR)-based intervention in enhancing personal safety skills among Deaf elementary school students in Saudi Arabia. Deaf children often face increased safety risks due to communication barriers, and while safety education is essential, limited research has explored the use of immersive tools like VR to support learning in this population. The aim of this quasi-experimental study was to evaluate the impact of a structured, visual, and interactive training program on three domains: street crossing, road and market safety, and school safety. A total of 22 students in grades 1 to 3, all using Saudi Sign Language as their primary communication method, participated in the study. The intervention group received a combination of visual lessons and VR-based simulations, while the control group followed traditional instruction methods. Pre- and post-tests were used to assess skill acquisition. Results showed that the experimental group experienced significant improvement across all safety domains, with the most substantial gain in street crossing skills, where the group achieved a perfect post-test mean score. MANOVA analysis confirmed the intervention's effectiveness, independent of age or presence of additional disabilities. These findings underscore the value of integrating VR and accessible technologies into safety education for Deaf students. The study contributes to inclusive education practices by demonstrating that tailored, technology-enhanced programs can effectively support the development of critical life skills in students who are deaf or hard of hearing.

Keywords: Deaf students, Inclusive education, Personal safety skills, Sign Language, Virtual reality in education.

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1. Introduction

Research links non-academic skills to improved academic performance, higher employability, and better physical and mental health [1]. They complement cognitive abilities and are essential for navigating both school and the workforce [1, 2]. Childhood traits such as attention and self-regulation are associated with modest gains in academic and psychosocial outcomes, with reported effect sizes ranging from 0.2 to 0.4 standard deviations [2, 3]. Evidence also points to a bidirectional relationship between executive function, social-emotional skills, and academic achievement [4]. Despite growing interest, much of the existing research is limited by low methodological quality and inadequate control of confounding variables. There is a need for more rigorous studies to identify effective strategies for fostering these skills [2, 3]. Moreover, potential biases such as small sample sizes and publication bias may inflate reported effects. Targeted interventions can support the development of non-academic skills, particularly among disadvantaged populations [2, 3]. Integrating life skills into classroom instruction and training teachers to nurture these abilities has shown promise [5]. Programs focusing on life skills have led to improvements in self-awareness, creativity, and critical thinking among high school students [2, 6, 7]. Road safety for children is a critical concern worldwide, as road traffic accidents remain a leading cause of injury and death among young individuals. The fatality rate due to road traffic crashes in Saudi Arabia has increased significantly, with the WHO reporting a rise from 17.4 to 27.4 fatalities per 100,000 people over the last decade [8, 9]. This rate is notably higher than in many developed countries and neighboring Gulf states. In the Eastern Province, the year 2012 recorded the highest number of crashes, with the Al-Ahsa region experiencing a disproportionately high number of incidents. Severe crashes predominantly occur outside city centers on urban highways [10].

1.1. Children's Perception and Education

Children, especially those under 9 years old, often struggle to identify dangerous road-crossing sites. They tend to focus only on visible cars and may not recognize other hazards such as blind spots or complex junctions. This highlights the need for targeted road safety education [11]. Road Safety Education (RSE) is crucial in shaping children's road behaviors. Studies indicate that while knowledge of traffic rules alone does not significantly predict safe road behavior, factors such as age, attitudes towards road safety, and risk perception play a significant role. This highlights the need for comprehensive RSE programs that address these factors at both school and community levels [12]. RSE should be age-appropriate and evolve as children gain independence. Practical skills for pedestrians and cyclists should be taught early, with more advanced skills introduced as children mature. Parents play a crucial role in modeling safe behavior and reinforcing road safety education [13].

1.2. Education and Role of Parents

Teaching children about road safety is essential and should be tailored to their developmental stages. This education should start with basic pedestrian skills and evolve to include more complex skills as children grow older [14]. Parents play a vital role as role models, demonstrating safe behaviors such as using seat belts and following traffic rules [15]. The presence of adults significantly influences children's behavior on the road. Without supervision, children are more likely to engage in risky behaviors, underscoring the importance of adult guidance in ensuring children's safety [16].

1.3. Risks of Language Delay in Deaf Children and the Limitations of Cochlear Implants

The health and language development of most Deaf children are critical concerns in the debate over cochlear implants [17, 18]. While deaf infants born to signing deaf parents typically receive accessible language from birth, 96% are born to hearing, non-signing parents [19]. These children face a high risk of language delay. Medical professionals often recommend cochlear implantation and advise families to rely solely on speech and hearing. This guidance can give parents a false sense of security, leading them to believe a CI will effectively make their child "hearing." However, outcomes with CIs are highly variable. A CI alone often fails to provide consistent and sufficient language input for typical development [17]. Many children with unilateral or bilateral cochlear implants do not receive adequate spoken language exposure, even after years of auditory training and speech therapy with families and professionals [19, 20].

1.4. Sign Language Use Among the Deaf Community in Saudi Arabia

Deaf individuals around the world communicate using sign languages and fingerspelling systems. In Saudi Arabia, the local Deaf community primarily uses Saudi Arabian Sign Language (SASL). In educational settings, however, teachers often employ Unified Arabic Sign Language (ARSL), a standardized system developed by the government for instructional purposes. SASL is one of several Arabic sign languages used across the region. Just as spoken Arabic includes many dialects, Arabic sign languages also vary widely. Despite debates over the use of regional sign language dictionaries, research suggests that many of these sign languages share common grammatical structures and linguistic features [21]. Differences between them are largely geographic, reflecting variations in local vocabulary, cultural expressions, and place-specific signs [22].

2. Method

2.1. Study Design and Subjects

The study utilized a quasi-experimental research design, which shares similarities with true experimental research but does not involve the random assignment of participants to treatment groups [23]. In quasi-experimental designs, the independent variable is manipulated before measuring the dependent variable, which helps address issues related to directionality. Specifically, this study employed a pretest-posttest design, where the dependent variable was assessed both before and after the intervention was applied.

The participants in this study were children attending a school for the Deaf, enrolled in elementary levels ranging from grades 1 to 3. All participants were Deaf and used sign language as their primary mode of communication, specifically

Saudi Sign Language. A subset of the children had additional disabilities alongside deafness. The intervention was implemented during the second semester of the 2024/2025 academic year and spanned three days. Prior to participation, informed consent was obtained from all parents to allow their children to be involved in the intervention.

2.2. Inclusion and Exclusion Criteria

The inclusion criteria for participation required that children be enrolled in K1 to grade 3 at a school for the Deaf, have a diagnosis of deafness, and primarily use Saudi Sign Language as their main mode of communication. Additionally, parental consent was required for participation in the intervention. The exclusion criteria included children who did not primarily use Saudi Sign Language, those whose parents did not provide consent, children whose disabilities prevented active participation in the intervention activities, children who missed at least one classroom session during the intervention period, and children who did not complete both the pretest and posttest assessments.

2.3. Study Approach

For the test, teachers asked participants questions related to three domains of safety: street crossing safety skills, safety skills in the road and the market, and safety skills at school. Each domain consisted of specific targeted skills, as detailed in Table 1. After the pretest, students were divided into two groups: a control group and an experimental group, with 11 students in each group. The learning sessions began with lessons using pictures and visual materials to introduce and explain safety skills, followed by activities using Virtual Reality (VR) games to simulate real-life situations. For the domains of Street Crossing Safety Skills and Safety Skills in the Road and the Market, VR games related to the specific skills were available and utilized. However, for the domain of Safety Skills at School, no VR game related to the skills was available; therefore, the teacher relied solely on pictures and visual media to clarify the concepts. Following the instructional phase, both groups completed a posttest covering all three safety domains.

Table 1.
Road Safety Skills by Dimension.

Road Safety Skills	
Domain	**Skills**
Awareness and Observation	• Look both ways (left, right, left again) before crossing. • Identify traffic signals and pedestrian signs. • Recognize safe crossing zones (crosswalks, pedestrian bridges). • Understand vehicle speed and distance.
Safe Crossing Behaviors	• Before crossing, stop at the curb. • Cross only at designated pedestrian paths. • Walk, don't run, across streets. • Maintain eye contact with drivers when possible.
Decision-Making in Crossing	• Judge when it is safe to cross based on traffic flow • Understand the dangers of distractions (phones, music) • Wait for the green pedestrian signal
Safety Skills in the Road and the Market	
Domain	Skills
Pedestrian Safety on Roadsides	• Walk on sidewalks or the far edge facing traffic if no sidewalk. • Stay alert in narrow or high-traffic areas. • Avoid walking too close to moving vehicles. • Walk carefully and hold your guardians' hands in the busy parking lot.
Market and Crowded Area Safety	• Stay with a guardian or group in busy markets. • Be cautious around delivery vehicles and carts. • Avoid sudden movements or running in crowded areas.
Dealing with Unpredictable Situations	• Know how to ask for help or directions if lost • Recognize emergency personnel or safe places (shops, security points) • Avoid unnecessary interactions with strangers
Safety Skills at School	
Domain	Skills
Safety in School and Classrooms	• Walk, don't run, in hallways. • Follow rules for line formation and transitions. • Keep hands and feet to oneself to avoid accidents.
Playground and Recess Safety	• Use equipment as intended • Be aware of your surroundings while playing • Respect other children's space and safety
Emergency Awareness	• Know evacuation routes and signals (fire drills, etc.) • Report unsafe behavior or damaged facilities • Stay calm and follow adult instructions in emergencies

2.4. Virtual Reality Game

The researcher explored available VR games to identify a suitable option for the study. For more details on the selection criteria, see Table 2. The researcher chose the *Virtual Road World* application developed by Cardiff University, Road Safety, because it is appropriate for the targeted age group, free to use, accessible without the need for VR goggles, and compatible with devices such as the iPad. The game was developed by Dr. Catherine Purcell, Senior Lecturer in Occupational Therapy at the School of Healthcare Sciences, and was designed to enhance road safety educational practices through interactive simulation experiences.

Table 2.
Comparative Summary of VR-Based Road Safety Applications for Educational Use.

Figure	Dimensions	Stability of internal consistency
1	The first dimension: street crossing safety skills	0.90
2	The second dimension: safety skills on the road and in the market	0.92
3	Third Dimension: Safety Skills at School	0.89
	Total Grade	0.92

3. Result

A value of 1 to 3 was assigned to the responses for each question, with 1 indicating "never," 2 indicating "sometimes," and 3 indicating "always." Indicators of internal consistency reliability for the Personal Safety Skills Scale for Deaf Students are based on Cronbach's alpha coefficient. For more details, see Table 3. The intervention group consisted of 11 male students who are Deaf and enrolled in grades 1 to 3. All participants were born Deaf and used Saudi Sign Language as their primary mode of communication. An additional 11 students who met the same criteria were assigned to the control group for comparison purposes.

Table 3.
Indicators of Internal Consistency Stability of the Scale of Personal Safety Skills for Deaf Students Through the Cronbach Alpha Equation.

Application Name	Platform	Price	Languages
UAB Youth Safety Lab VR Pedestrian Simulator (Univ. of Alabama at Birmingham) – *Immersive street-crossing training app*	Mobile VR (Google Cardboard + smartphone)	N/A (Research prototype; NIH-funded, not publicly sold)	English (used in U.S. study; also piloted in China with localized content)
Virtual Road World (Cardiff University, Road Safety Trust) – *Road crossing game with AR/VR for primary students*	Mobile (iPad/tablet; AR/VR using device motion)	Free	English
"Woodlands" VR Road Safety Game (TU Dublin) – *Serious game teaching safe crossings*	PC-based VR (immersive headset)	N/A (Educational research project)	English
VR Street Crossing Training Program (University of Guelph) – *Interactive VR simulation with feedback for crossing streets*	PC-based VR (immersive headset with 3D goggles)	N/A (Research program, not commercial)	English
"Safer Kids VR" – Safety ville (Centre VR & Bournemouth Univ.) – *VR experience guiding children through a town to practice road safety*	PC-based VR (on-site VR arcade setup)	One-time session fee (approx. $27 per child)	English
RSA Road Safety Learning Portal ("Road Safety-Verse," Ireland) – *Metaverse-style 3D world for road safety education*	Multi-platform: Web browser (desktop/tablet/mobile) and optional VR headset	Free (Government-funded educational resource)	English (Ireland)

The data in Table 4 shows the mean scores and standard deviations for both control and experimental groups on pre- and post-tests across three safety skill dimensions: street crossing, road and market safety, and school safety. Both groups started with relatively similar pre-test scores. However, after the intervention, the experimental group demonstrated remarkable improvements across all dimensions, particularly in street crossing skills, where their mean score increased from 2.00 to 3.00. In contrast, the control group showed only slight improvements.

Table 4.
Means and Standard Deviations for the Control and Experimental Groups on the Pre- and Post-Tests.

Dimension	N	Control Pre-test (M)	Control Pre-test (SD)	Control Post-test (M)	Control Post-test (SD)	Experimental Pre-test (M)	Experimental Pre-test (SD)	Experimental Post-test (M)	Experimental Post-test (SD)
Street Crossing Safety Skills	11	1.73	0.41	2.14	0.23	2.0	0.32	3.0	0.0
Road and Market Safety Skills	11	2.18	0.34	2.23	0.56	2.23	0.34	2.82	0.34
School Safety Skills	11	1.91	0.3	2.32	0.72	2.14	0.23	2.95	0.15
Overall Scale	11	1.82	0.34	2.32	0.46	2.0	0.22	2.95	0.15

The multivariate analysis of variance (MANOVA) results in Table 5 suggest that the training program had a significant positive effect on the experimental group compared to the control group across all dimensions of personal safety skills for Deaf students. Significant differences were observed in street-crossing, road and market, and school safety skills, as well as in the overall scale, favoring the experimental group. Age and the presence of additional disabilities did not show significant effects on safety skills. However, prior participation in similar training programs significantly influenced performance in street-crossing safety and the total scale. These findings suggest that targeted intervention can meaningfully enhance safety awareness and behavior in Deaf students, particularly in practical, real-world contexts.

Table 5.
Results of the Multivariate Analysis of Variance (MANOVA) of the effect of the training program on the experimental and control groups. The table shows the pre- and post-test means for both groups on the Personal Safety Skills Scale for Deaf Students, attributed to group, age, presence of additional disabilities, and previously attended training programs.

Source of Variance	Dimension	Sum of Squares	df	Mean Square	F Value	Significance
Group (Control, Experimental)	Street-Crossing Safety Skills	3.55	1	3.55	40.06	0.00*
	Road and Market Safety Skills	1.11	1	1.11	5.16	0.034*
	School Safety Skills	2.05	1	2.05	11.57	0.003*
	Total Scale	1.84	1	1.84	13.97	0.001*
Age	Street-Crossing Safety Skills	0.084	1	0.084	2.40	0.081
	Road and Market Safety Skills	0.60	1	0.60	4.27	0.108
	School Safety Skills	0.051	1	0.051	1.40	0.302
	Total Scale	0.038	1	0.038	2.40	0.196
Previously Attended Training Programs	Street-Crossing Safety Skills	0.15	1	0.15	9.60	0.036*
	Road and Market Safety Skills	0.234	1	0.234	1.67	0.266
	School Safety Skills	0.051	1	0.051	1.40	0.302
	Total Scale	0.15	1	0.15	9.60	0.036
Other Disabilities	Street-Crossing Safety Skills	0.039	1	0.039	2.49	0.189
	Road and	0.088	1	0.088	0.623	0.474

	Market Safety Skills					
	School Safety Skills	0.108	1	0.108	2.97	0.160
	Total Scale	0.061	1	0.061	3.90	0.120

In Table 6, the data indicate significant improvements in personal safety skills among Deaf students in the experimental group following the intervention. For the full scale, the experimental group's mean score increased from 2.00 to 2.95, with a statistically significant difference (p = .000), compared to a smaller increase in the control group from 1.82 to 2.32 (p = .004). Specifically, the most substantial gain was observed in the "Street Crossing Safety Skills" dimension, where the experimental group reached a perfect post-test mean of 3.00. The "Road and Market Safety Skills" and "School Safety Skills" also showed notable improvements in the experimental group with significant p-values (.000), unlike the control group, which did not demonstrate statistically significant gains in these areas.

Table 6.
Differences between pre- and post-measurement means for the experimental and control groups in the responses of the study sample on the personal safety skills scale for Deaf students and its dimensions based on the results of the paired samples t-test.

Variable	**Group**	**Pre-test Mean**	**SD**	**Post-test Mean**	**SD**	**Difference (Pre-Post)**	**Significance**
Total Score (Full Scale)	Control	1.82	0.34	2.32	0.46	-0.50	.004*
	Experimental	2.00	0.22	2.95	0.15	-0.95	.000*
	Difference	-0.18	0.12	-0.64	0.15		
Street Crossing Safety Skills	Control	1.73	0.41	2.14	0.23	-0.40	.011*
	Experimental	2.00	0.32	3.00	0.00	-1.00	.000*
	Difference	-0.27	0.16	-0.86	0.07		
Road and Market Safety Skills	Control	2.18	0.34	2.23	0.56	0.045	.796
	Experimental	2.23	0.34	2.82	0.34	-0.59	.000*
	Difference	-0.045	0.15	-0.59	0.20		
School Safety Skills	Control	1.91	0.30	2.32	0.72	-0.40	.108
	Experimental	2.14	0.23	2.95	0.15	-0.82	.000*
	Difference	-0.23	0.11	-0.64	0.22		

Note: *Significant at the level ($\alpha \leq 0.05$)*

4. Discussion

Both groups began with relatively comparable pre-test scores. Following the intervention, however, the experimental group showed significant improvement across all measured areas, most notably in street crossing skills, where their average score rose from 2.00 to 3.00. Similar results were observed in a single-subject design study by Wright and Wolery [24] in which a student with disabilities quickly acquired basic road safety skills in a classroom setting and successfully generalized those skills to an outdoor environment. It is widely considered best practice to intentionally design interventions that promote the transfer of learned skills across different contexts. Several studies have demonstrated that VR-based interventions can effectively improve street-crossing skills in children with diverse learning needs, including those with Autism. Fornasari et al. [25] developed a VR training program consisting of two 45-minute sessions aimed at enhancing pedestrian safety. Their results indicated positive gains in the participants' understanding and behavior in simulated traffic situations. In another study, Tzanavari et al. [26] utilized a more immersive setup through the use of a VR CAVE (Cave Automatic Virtual Environment), a room-sized, multi-screen virtual reality system. This setup provided a highly realistic and interactive experience where children learned how to cross pedestrian roads safely. The training involved eight sessions, offering repeated exposure and structured guidance. The intervention concluded with a real-life session at an actual pedestrian crossing to assess whether the children could generalize the safety skills acquired in the VR environment to the real world. Similarly, Vogel et al. [27] evaluated a VR pilot program designed specifically for Deaf and Hard of Hearing (DHH) children aged 5 to 10. The program aimed to teach crucial life skills such as safely crossing the street, responding to fire drills, and avoiding dangerous strangers. Over a six-week period, different safety scenarios were targeted weekly in a VR classroom setting. The evaluation examined usability, enjoyment, and knowledge transfer. Results showed that the system was well-liked, user-friendly, and encouraged enthusiastic participation. Students completed tasks accurately, demonstrating learning gains. While some usability challenges were identified, the study affirmed VR's potential in teaching life skills to DHH and other at-risk populations. Collectively, these findings highlight the value of VR in delivering experiential, visually rich learning for students who benefit from visual instruction.

The training program had a significant positive impact on the experimental group compared to the control group across all dimensions of personal safety skills for Deaf students. Notably, substantial improvements were observed in three key areas. First, street-crossing skills improved significantly, aligning with previous research on the enhancement of pedestrian road safety knowledge [28-30], particularly in the study by Gao et al. [28], which focused specifically on individuals with hearing loss. In addition, improvements in road and market safety skills were consistent with the findings of Meir et al. [29] who demonstrated that training programs can enhance children's ability to perceive and respond to potential risks. For example, at unsignalized T-intersections, individuals with hearing loss who received training were observed to proactively check for hazards on slip roads before crossing, suggesting that the intervention effectively developed their risk perception abilities. Lastly, school safety skills also showed marked improvement following the intervention. This outcome is consistent with the findings of Agran et al. [31], who emphasized the importance of teaching essential safety skills, such as self-medication and workplace safety, to students with disabilities. Similarly, Asher et al. [32] highlighted the necessity of developing tailored safety procedures to meet the specific needs of students during emergencies and to ensure their safety within school environments.

5. Conclusion

This study demonstrated the effectiveness of a targeted safety skills intervention using visual materials and VR technology in enhancing the personal safety skills of Deaf students in elementary grades. The quasi-experimental design revealed significant improvements across all three safety domains, such as street crossing, road and market safety, and school safety for students in the experimental group. Notably, the most substantial gain was observed in street crossing skills, where the post-test mean reached the maximum score. These findings align with previous research emphasizing the value of structured, contextually relevant training for individuals with hearing loss. The study highlights the importance of using accessible, engaging, and immersive teaching tools such as VR simulations to support skill acquisition among Deaf learners. Moreover, the observed lack of influence from age or additional disabilities reinforces the broad applicability of such interventions. Given these outcomes, educators and policymakers are encouraged to integrate VR and other interactive visual tools into safety curricula for Deaf students. Future research should explore the long-term retention of these skills and their transfer to real-world settings, as well as expand the intervention to include more diverse student populations.

6. Limitations

Even with the observed improvements, several limitations should be acknowledged. First, the study involved a small sample from a single school, limiting the generalizability of the findings. Second, the intervention was implemented over a short time frame (three days), which may not reflect long-term learning or retention. Additionally, although VR games were successfully utilized for two safety domains, the lack of VR content for school safety limited the consistency of the intervention across all areas. Future studies should consider developing custom VR applications tailored to school-based setups, incorporating elements aligned with Saudi traffic laws and culturally relevant characters that reflect Saudi society, rather than Western contexts.

6.1. The Future of Practice Research

Despite these limitations, the study highlights the importance of using accessible, engaging, and immersive teaching tools such as VR simulations to support skill acquisition among Deaf children. For future practice, educators and policymakers are encouraged to integrate VR and other interactive visual tools into safety curricula for Deaf students. It is also essential to provide ongoing training for teachers on how to implement such technologies effectively. Further research should investigate the long-term retention and real-world application of safety skills, examine scalability across different educational settings, and consider the perspectives of families and educators in evaluating the program’s broader impact.

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