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SOCIAL SERVICES, HEALTH AND SPORTS

"DON'T BE LIKE FROGGER"

A Rapid Review on the Use of Serious Game for Road Safety Education in Children

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Abstract

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Abstract

Objective: Serious games might have the potential to educate children in road safety knowledge and skills. This review aimed to categorize existing serious games and their effects on road safety skills in children.

Materials and Methods: The author systematically searched PubMed and CINAHL Complete for publications that evaluated serious games to improve road safety skills in children. A taxonomy by De Lope & Medina-Medina was used to classify the identified games.

Results: The author identified five studies, evaluating four unique serious games. Most of the studies targeted pedestrian safety skills in children, while only one study targeted child bicyclists’ situational awareness. Four studies involving child pedestrians found largely positive impacts of serious games on safety skills but displayed mixed results when participants were measured at the streetside testing. The only study targeting child bicyclists did not display a positive outcome.

All studies used simulation games as interventions, while most incorporated the virtual reality technology for added ’realism.’ All studies lack documentation of the game development process, inclusions of key features of ’great games’ (such as narrative context and game-based gaming), and measurement of participants’ experiences while playing the games.

Conclusions: The evidence from a number of studies suggests that games may have positive effects on road safety-related outcomes, particularly road crossing skills. However, further studies are required to assess the translationalability of the positive impacts of serious games in real-life settings. Researchers should also utilize existing evidence in serious games to further improve the educational approaches.

Keywords

road safety education, serious game, educational approach

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1 INTRODUCTION

In 2008, the World Health Organization (WHO) released the seminal "World report on child injury prevention." The WHO recognizes that child injuries are an increasing global public health concern. They are a substantial subject of concern in early childhood and beyond. Each year, hundreds of thousands of children die from injuries, while millions more endure the consequences of non-fatal injuries. Injuries are the leading cause of death in children aged 10 to 19. (World Health Organization, 2008).

Among different kinds of child injuries, road traffic injuries demand close attention. Based on a study performed by WHO in 2004, road traffic injuries contributed to 22.3% of global child injury deaths, the highest percentage among various classifications of child injury (World Health Organization, 2008). In high-income countries, the unintentional injury death rate per 100 000 children caused by road traffic injuries was 7.0, almost 6-times higher than the death rate caused by drowning (World Health Organization, 2008). Furthermore, the death rate significantly increased to 11.0 in low-income countries (World Health Organization, 2008). In comparison to non-communicable and communicable diseases, road traffic injuries were the main cause of death for 15–19-year-olds and the second largest cause of death for 10–14-year-olds. (World Health Organization, 2008).

While death is the most visible manifestation of injury, the WHO reminds us that it is not the only nor the most frequent result. Injury consequences are often shown graphically as a pyramid, with death at the apex, hospitalized injury in the middle, and non-hospitalized injury at the base (World Health Organization, 2008). Hence, recognizing the urgent need to prevent and reduce the consequences of road traffic injuries, in 2010, the United Nations declared the period 2011–2020 as the "Decade of Action for Road Safety" (United Nations, 2010). This commitment was extended until 2030, when the UN declared the period 2021-2030 as the "Second Decade of Action for Road Safety" and established a worldwide target of at least a 50% reduction in road traffic fatalities and injuries (United Nations, 2020). The declaration presents an opportunity for research in road traffic injury interventions in the years to come.

WHO recommends several intervention modalities to prevent road traffic injuries (See sub-section 1.1.4). One of the modalities is road safety education. According to the latest research on road safety education, a strategy that emphasizes behavior is more likely to benefit younger children since it focuses on developing practical skills. In addition, children learn best when they are exposed to strategies that encourage problem-solving and decision-making. (World Health Organization, 2008). Among different examples of practical educational approaches quoted by WHO, the use of simulated environments, where children are taught pedestrian skills in a safe space off the road, opens the possibility for integration with technology, such as virtual and augmented reality technologies (Schwebel & McClure, 2010; World Health Organization, 2008).

In the studies of technology-assisted educational approaches, serious games have undergone rapid development in recent years. Serious games can be defined as "games whose main characteristic is to teach or inform specific concepts of disciplines or to train operational and behavioral skills of the player" (Morais et al., 2020). In various fields of health education, researchers have evaluated the usage of serious games (Derksen et al., 2020; Morais et al., 2020; Theng et al., 2015). However, no review has assessed the usage of serious games and gamification elements for road safety education in children to the author's knowledge. Therefore, this thesis aims to evaluate and review relevant road safety educational approaches in children from the perspective of serious games and explores ideas to improve the effectiveness of such approaches.

1.1 Road Traffic Injury in Children

1.1.1 Epidemiology

According to the WHO Global Burden of Disease research, about 1.3 million people of all ages died in road traffic accidents globally in 2004, with an additional 50 million injured or incapacitated (World Health Organization, 2008). Road traffic injuries are currently estimated to be the ninth leading cause of death globally, rising to the seventh leading cause of death by 2030 (World Health Organization, 2015). This trend is driven by an increase in road fatalities in low- and middle-income nations, notably in developing economies where urbanization and motorization are accompanied by strong economic development. Many of these nations' requisite infrastructure expansions, regulatory revisions, and enforcement levels have not kept up with increased motor usage (World Health Organization, 2015). While South-East Asia and the Western Pacific accounted for almost 60% of all road traffic deaths, Africa and the Eastern Mediterranean had the highest rates of road traffic fatalities per 100,000 inhabitants (World Health Organization, 2008).

Children accounted for 21% of all road traffic fatalities worldwide. Globally, road fatalities account for almost 2% of all child mortality. However, there are substantial geographic variances. For example, in South-East Asia, the percentage of children killed in road traffic accidents is 1.3%, whereas it is as high as 4.7% in the Americas. Around 93% of child traffic fatalities occur in low- and middle-income nations. From an absolute number perspective, South-East Asia and Africa Regions, as well as the low- and middle-income nations of the Western Pacific Region, accounted for more than 60% of all child road traffic deaths globally in 2004 (World Health Organization, 2008). However, the statistic paints a different picture if we observe the rate of child road traffic fatalities per 100,000 population. The rate of road traffic deaths among children in the African Region is 19.9 per 100,000 people, about 1.8x that of the worldwide average of 10.7 per 100,000 population (World Health Organization, 2008).

As mentioned previously, road traffic accidents are the main cause of death among 15–19-year-olds globally and the second largest cause of death among 5–14-year-olds. Globally, road traffic mortality rates increase with age, a trend that reflects how children of various ages utilize the road. Children under nine are more likely to travel with their parents, whether in vehicles or on foot. Children increasingly gain independence as they get older, first as pedestrians, then as bicyclists, motorcyclists, and finally as drivers. Injury rates are higher among children aged ten years and older because of their increased mobility and tendency for risk-taking behaviors (World Health Organization, 2008).

Apart from age, children's road usage habits differ by country. The difference is reflected in the percentage of child road traffic injuries measured by the role of children in the accidents. Children are usually found as motor vehicle occupants in road traffic accidents in higher-income countries. For example, a retrospective study analyzing 1,243 accidents involving children aged 0-16 years in Singapore documented from 2011 to 2014 observes that 60.4% of the victims are motor vehicle passengers, while only 28.5% and 9.9% of the victims are pedestrians and cyclists, respectively (Lee et al., 2018). The statistic is comparable to the findings in Canada. Using the national Canadian hospital discharge data from 2006 to 2012, researchers observe that the average hospitalization rate due to road traffic accidents where the children are vehicle occupants is 22.05 per 100,000 population (Fridman et al., 2018). The average rates are lower for cyclist-related and pedestrian-related injuries; 17.58 and 7.51 per 100,000 population, respectively (Fridman et al., 2018).

In comparison, road traffic accidents in low to middle-income countries tend to occur in children who are pedestrians. For example, in a retrospective study examining 709 cases of road traffic fatalities in children less than 19 years old that occurred in the Chandigarh zone of northwest India from 1974 to 2013, researchers find most of the victims are pedestrians (47.6%), followed by two-wheeler occupants (33.4%) and light wheeler occupants (10.4%) (Singh et al., 2016). The same study also observes that most fatal accidents occur between 12 pm and 8 pm, attributed to increased numbers of child road users after school closure and motor vehicles used by workers coming home from the workplace (Singh et al., 2016).

1.1.2 Risk Factors

Many factors increase the risk of road traffic injury specific to children. These risk factors are usually categorized into child factors, vehicle and safety equipment factors, environmental factors, and socioeconomic factors.

A. Child factors

Due to their relative physical fragility, children are more susceptible to the consequences of injury than adults. Additionally, children's relative diminutive physical stature may provide challenges, as it hinders their capability to see or be seen above certain heights by drivers of parked vehicles. This factor has been observed in past child pedestrian accidents. Furthermore, children's sensory capabilities are still developing. Consequently, their ability to integrate sensory inputs from their peripheral vision and hearing is harmed, increasing their likelihood of being involved in a motor vehicle accident. (World Health Organization, 2008).

Children are also still undergoing cognitive development. For example, while young children between the ages of five and seven years may have mastered the concepts of speed and distance, they cannot identify unsafe crossing situations based only on the visual presence of vehicles. Additionally, they are unlikely to evaluate the presence of approaching vehicles effectively. These cognitive processes seem to be more developed in individuals aged 11 years and older, who can recognize a dangerous road section and display the judgment required for road safety. Additionally, children above the age of 12 years old have the potential to change their actions when confronted with a circumstance requiring them to perform more than one task (World Health Organization, 2008).

B. Vehicle and safety equipment factors

Child passengers of cars who are properly secured are much less likely to be killed or wounded than children who are not restrained (World Health Organization, 2015). Children should be secured in restraints suitable for their age, weight, and height. Regrettably, the incidence of proper child restraint usage in motor vehicles varies significantly across countries. This is most likely because certain parts of the globe lack child restraint regulations. For example, only a few countries in South-East Asia and the Eastern Mediterranean regions have enacted child restraint legislation (World Health Organization, 2015). Furthermore, compliance remains a significant challenge even with enacted child restrain legislation. Cost of child restraints and difficulty in installing the devices unto vehicles are quoted as reasons for non-compliance (World Health Organization, 2015).

Similarly, child bicyclists and passengers of two-wheeled vehicles (such as motorcycles) should wear properly fitted helmets. Unfortunately, there is a lack of adequately sized helmets in countries with a higher percentage of child passengers of two-wheeled vehicles (World Health Organization, 2008). For example, in an analysis of 6,800 video samples from school gates and typical roads in Ho Chi Minh City, Vietnam, Vu & Man Nguyen (2018) find that 75% of the kindergarten children and more than 50% of primary school students who are passengers of motorcycles do not wear helmets.

C. Environmental factors

Today, motorization and urbanization are growing across a large portion of the globe, especially in developing countries. Increased and faster mobility is often the priority, whereas safe mobility – and notably the protection of children – is seldom considered. The road network is built without attention to children's specific needs in many locations. As a result, numerous environmental factors may contribute to the hazard of child road users. For example, there is a lack of playgrounds, which unintentionally forces children to play on the street. There is also a lack of infrastructure to divide road users (e.g., bike lines and sidewalks for pedestrians) and a lack of speed limits, especially in residential areas where children play or go to and from school (World Health Organization, 2008).

D. Socioeconomic factors

While younger children may accept risks unintentionally due to a lack of adequate discernment skills, older children and teenagers may consciously seek out danger. Risk-taking behavior may enable children to acquire control of their life. As a result of this behavior, they are at a higher risk of road traffic injury (World Health Organization, 2008). This growth is sometimes followed by an increased possibility for older children to enter a period in which their parents' influence diminishes, and they begin to find and establish their independence. This change may result in a lack of adult supervision, often highlighted as a risk factor for road traffic injury among minors (World Health Organization, 2008).

1.1.3 Existing Intervention Modalities

There are several existing intervention modalities to prevent and reduce the rate of child road traffic injuries and fatalities. The first intervention modality is engineering measures to address environmental factors that increase the risk of child road traffic accidents. Such measures include implementation of infrastructural changes that may reduce the speed of vehicles in residential and school areas (e.g., speed humps), increase in numbers of designated pedestrian crossings, the establishment of safe playgrounds away from the roads, and exclusive bicycle and motorcycle lanes (World Health Organization, 2008). While 138 of 180 countries studied by WHO evaluates existing road network for safety, much of the best practices in infrastructure design to improve road safety discovered in developed countries have yet to be implemented in low and middle-income countries (World Health Organization, 2015).

The second intervention modality is enacting and reinforcing legislation and standards targeting child road safety. Examples of such measures include reinforcing strict child restraint laws, raising the age limit for motorized two-wheeler licensing, and making it mandatory for child occupants of motorcycles to wear helmets (World Health Organization, 2008). WHO (2015) recognizes that many countries should still strive to strengthen road safety legislation through more efficient drafting of new laws, revision of existing legislation to meet best practices, and more effective enforcement to increase success rates of road safety laws.

The last intervention modality is road safety education. Historically, road safety education has taken place in classroom settings, focusing on teaching students the rules of the road (e.g., road signs, designated pedestrian crossings). However, in recent years, social scientists specializing in injury prevention have adopted a more integrative approach, incorporating elements from the disciplines of child development, educational theory, and behavioral theory (World Health Organization, 2008). This development has resulted in educational approaches that teach children how to apply practical roadside skills in secure lifelike simulated environments.

1.2 An Introduction to Serious Game

1.2.1 Definition of Serious Games

Many researchers credit Clark Abt, an early US researcher in the area of games designed for training and education, for coining the term "Serious Game" and establishing the first clear definition of the term: *"Games may be played seriously or casually. We are concerned with serious games in the sense that these games have an explicit and carefully thought-out educational purpose and are not intended to be played primarily for amusement. This does not mean that serious games are not, or should not be, entertaining"* (Djaouti, Alvarez, Jessel, et al., 2011). Abt's definition of the term is often abridged to "games that do not have entertainment, enjoyment, or fun as their primary purpose" (Laamarti et al., 2014). In other words, serious games are differentiated from casual games in that they have a primary design objective other than amusement (Laamarti et al., 2014).

Laamarti et al. (2014) propose a more integrative definition of serious games. Similar to casual games, serious games should incorporate entertainment and multimedia components. What differentiates between a serious game and a casual game is its ability to convey the intended "serious" knowledge and skill through gaming experiences (Laamarti et al., 2014). Serious games are then differentiated from training simulation, computer games, and sports, as illustrated in FIGURE 1.

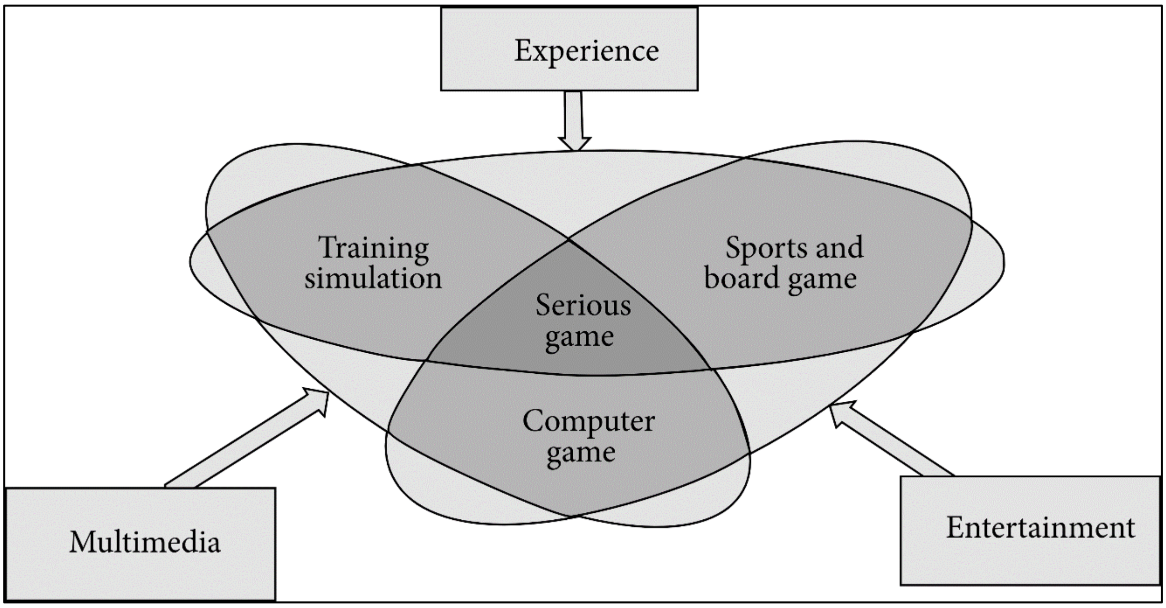

FIGURE 1. Definition of serious games (Laamarti et al., 2014, CC BY 3.0)

1.2.2 A Brief History of Serious Games

The US Military was the early adopter of serious games. In 1981, the American army worked with Atari to develop a simulation tool known as *The Bradley Trainer*, a customized version of the video game *Battlezone* (Wilkinson, 2016). The tool was used to train recruits to operate the Bradley Infantry Fighting Vehicles (Laamarti et al., 2014). Atari modified the tank found in the original 3D game to mimic the real-life military vehicles, armed with a chain-gun and a canon to match the military training purpose of the simulation tool (Djaouti, Alvarez, Jessel, et al., 2011). *The Bradley Trainer* can be considered as a predecessor of serious games.

Another famous predecessor of serious games is *The Oregon Trail*, an educational game developed by History teachers and was initially published by the Minnesota Educational Computing Consortium in 1971 (Djaouti, Alvarez, Jessel, et al., 2011). In the game, the player plays as an American pioneer traveling to Oregon in 1848. At the same time, the player will learn knowledge related to this period of American History (Djaouti, Alvarez, Jessel, et al., 2011). The game was an excellent example to show that a "serious" game can also be "popular and commercially successful."

The contemporary era of Serious Games started with the publication of the white paper *Serious Games: Improving Public Policy through Game-based Learning and Simulation* by Ben Sawyer and the launch of the Serious Games Initiative in 2002 (Wilkinson, 2016). Sawyer suggested using video games for contextual applications and the need for educational practitioners to inform the video game industry in such cases (Wilkinson, 2016).

Serious Games have evolved from a series of exploratory experiments in the areas of defense, education, advertising, and religion to a growing interdisciplinary field of study (Wilkinson, 2016). In 2013 alone, there were more than 1,200 academic papers related to Serious Games, an exponential increment compared to the decade earlier (see FIGURE 2). Serious Games have also gained a relatively successful presence in the video game industry. More than 300 serious games were published in 2012, 3x of the figure in the decade earlier (see FIGURE 3). The Serious Games market's value is predicted to reach a value of 10 billion Euros in 2015 (Laamarti et al., 2014).

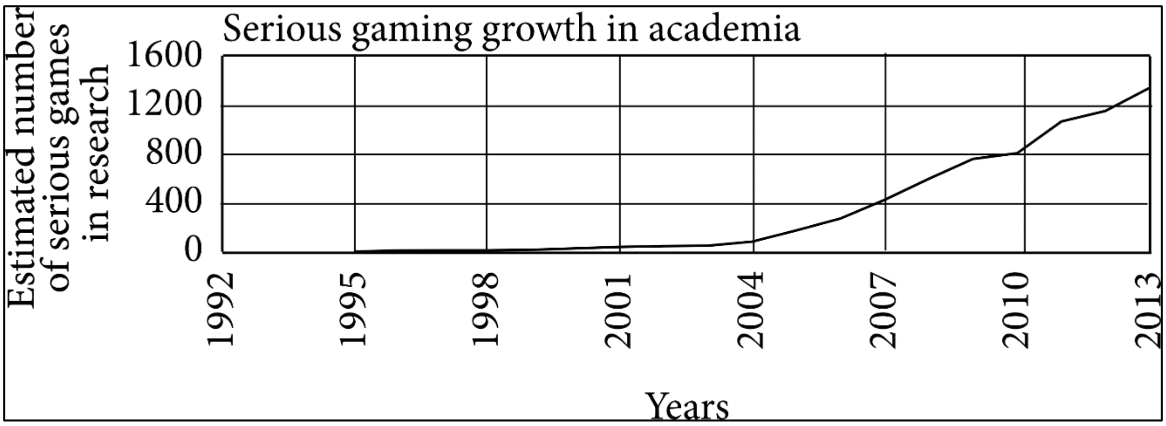

FIGURE 2. Serious games growth in the research field based on surveyed papers in ACM digital library and IEEE Xplore (Laamarti et al., 2014, CC BY 3.0)

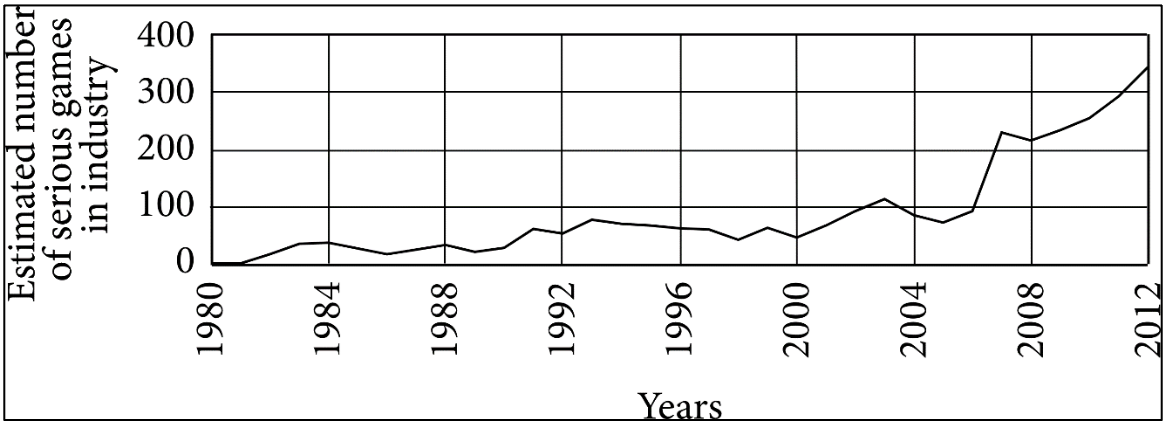

FIGURE 3. Serious games growth in industry (Laamarti et al., 2014, CC BY 3.0)

1.2.3 Taxonomy of Serious Games

There are several proposed taxonomy or classification systems for Serious Games. Laamarti et al. (2014) propose a relatively simple taxonomy system based on five criteria; activity, modality, interaction style, environment, and application area (FIGURE 4). In this classification system, serious games are categorized based on the type of activity performed by the players during the game (ACTIVITY), technologies or devices used to facilitate the player interaction (INTERACTION STYLE), characteristics of the environment encountered by the player (ENVIRONMENT), how the intended 'serious' knowledge or skill is communicated to the players (MODALITY), and the contextual purpose of the games (APPLICATION AREA) (Laamarti et al., 2014). The taxonomy system is intended to be used to classify serious games quickly.

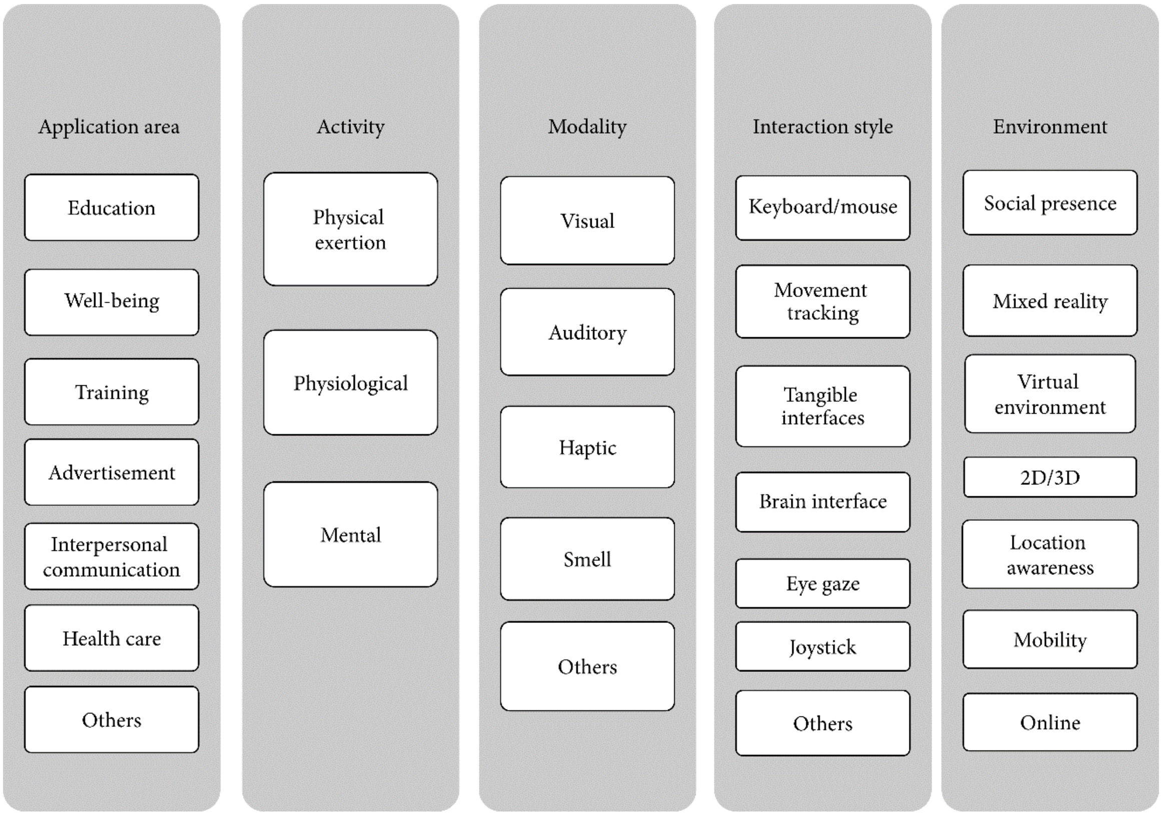

FIGURE 4. Taxonomy of serious games (Laamarti et al., 2014, CC BY 3.0)

Another well-known classification system for serious games is *the Gameplay/Purpose/Scope model*, usually referred to as *the G/P/S model* (Djaouti, Alvarez, & Jessel, 2011). The classification system was designed out of concerns that earlier taxonomy focuses solely on either the 'game' dimension of serious games, or the 'serious' dimension, that is the games' primary purpose (usually not for entertainment, as per the standard definition of the term) and target audience (Djaouti, Alvarez, & Jessel, 2011). The first aspect of the G/P/S model, *Gameplay*, focuses on whether a serious game is 'game-based' (presenting 'goals' for players to aim for) or 'play-based' (no 'goals' are present). The second aspect of the model, *Purpose*, classifies serious games based on the following objectives: a message or information broadcasting, training, and data exchange (i.e., collecting data from players). The last aspect of the model, *Scope*, refers to the intended target market of the serious games; is it specific audience groups (e.g., military, healthcare, art) or the general public (Djaouti, Alvarez, & Jessel, 2011).

After comparing and analyzing more than 14 different taxonomy systems for serious computer games, De Lope & Medina-Medina (2017) propose a more comprehensive taxonomy with 16 criteria to assist researchers in the knowledge organization on a conceptual level. The taxonomy considers criteria that have not been included in earlier proposals, including *Development Methodology* (which software development methodology adapted), *Deployment* (whether the software is installed in local computers or run from the Web), *Narrative* (degree and amount of narratives found in the game), and *License* (restriction on the use and redistribution of the software) (De Lope & Medina-Medina, 2017).

1.2.4 Existing Use Cases of Serious Game for Health Education in Children

There are several documented use cases of serious games for health education in children. In a systematic review analyzing studies related to serious games in asthma education for children, the authors include 12 relevant articles published from 1980 to 2015 (Drummond et al., 2017). Most studies document a high satisfaction rate towards the serious game studied and improved knowledge of asthma management (Drummond et al., 2017). However, the authors also conclude that the use of serious games is associated with little change in health-related behaviors among participants and no improvement in clinical outcomes (Drummond et al., 2017).

Serious games have also been studied for nutritional education among children. For example, a group of researchers in Mexico developed FoodRateMaster, a serious video game designed to improve nutritional knowledge and change food-intake behavior, and conducted a pilot study involving 60 children (Espinosa-Curiel et al., 2020). The group discovered that the game had improved nutritional knowledge among the participants and induced behavior change. Participants reported a higher frequency of eating healthy foods and a reduced frequency of consuming unhealthy foods postgame (Espinosa-Curiel et al., 2020). Furthermore, parents reported that the children also suggested changes in their diet (Espinosa-Curiel et al., 2020).

2 MATERIAL AND METHODS

The author conducted the rapid narrative review by adopting relevant elements from the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines (Page, McKenzie, et al., 2021; Page, Moher, et al., 2021) and adhering to SANRA (Scale for the Assessment of Narrative Review Articles) critical appraisal tool (Baethge et al., 2019).

2.1 Objectives

There as two general objectives of the review. First, to understand the overall effectiveness of road safety education in children from a serious game perspective. Second, to categorize serious games used in road safety education for children and identify gaps in game design and development documentation. The findings of this thesis will be used to inform future research that seeks to incorporate elements of serious games into existing educational approaches

2.2 Inclusion and Exclusion Criteria

The author searched for original research articles that analyzed serious games and educational approaches that incorporated game elements targeting road safety knowledge improvement and behavior change in children. The author modeled the inclusion and exclusion criteria using the PICOS (Population, Interventions, Comparisons, Outcomes, Study designs) tool. Regarding population, the author only included studies targeting children under the age of 18, as per UNICEF's definition (UNICEF, n.d.). Regarding interventions, the author included serious games and interventions that adopted game elements. The author excluded other kinds of games and any interventions that lacked game elements. The author included studies analyzing road safety educational approaches targeting pedestrians, bicyclists, and passengers of motor vehicles. Studies targeting children as drivers of motor vehicles were excluded, as there is significant variation on the minimum driving age globally (Williams, 2009). The author included both digital and analog education approaches.

Regarding comparisons, the author did not exclude any specific comparisons. In terms of outcomes, the author included research that assessed the impact of serious games and relevant educational interventions on road safety outcomes and omitted studies that solely reported usability ratings and player experiences. Regarding study designs, the author included studies with all research designs. The author only included studies in English and excluded studies published in other languages. The author applied a restriction on publication year. The author only included studies published from 2000 onwards, as limited studies involving digital approaches were published before 2000 (Zhang et al., 2018).

2.3 Search Strategy

PubMed and CINAHL Complete databases were systematically searched using the following search terminologies: ("road safety" OR "accidents, traffic" OR "pedestrians") AND ("child, preschool" OR "child" OR "adolescent" OR "pediatrics") AND ("education" OR "health education") AND ("game" OR "gaming" OR "game elements" OR "game mechanics" OR "gamification" OR "serious game" OR "video game" OR "mobile game" OR "computer game" OR "virtual reality" OR "virtual environment").

2.4 Study Selection

After removing duplicates, the author screened studies based on title and abstract and assessed the remaining retrievable articles' full text for eligibility. Zotero (Corporation for Digital Scholarship, Vienna, VA, USA) was used for screening and data management

2.5 Quality Appraisal

The author appraised the quality of each included study using the Quality Assessment Tool for Quantitative Studies (Thomas et al., 2004). Articles were not excluded based on the quality assessment.

2.6 Data Extraction and Analysis

For eligible full articles, the following data were extracted:

- Publication details
- Study design, setting, and participant characteristics (including age, sex, ethnicity/race, educational level)
- Study objective
- Details of interventions (including intervention and control groups
- Primary and secondary road safety-related outcomes

The author used the taxonomy proposed by De Lope & Medina-Medina (2017) to classify serious games and educational approaches used in the studies. The taxonomy was selected as it provided a controlled and comprehensive dictionary of classification criteria. APPENDIX 1 provides details of the taxonomy.

Some key features of the taxonomy enable the author to achieve the objective identified above: to identify gaps in the design and development documentation for serious games used in road safety education. First, the taxonomy provides direction on which serious game aspects to examine and consider. Second, the taxonomy defines a compendium of variables that may be explored and applied during the game design and development. Any missing documentation of the game aspects and selection of possible game design and development variables may be considered as gaps. Last, since the taxonomy uses a set of controlled and fixed terms, readers of the thesis from various groups (e.g., game developers, educators) can refer to the taxonomy to interpret and understand the review results (De Lope & Medina-Medina, 2017).

3 RESULTS

3.1 Study Inclusion

The PRISMA 2020 flow diagram (see FIGURE 5) shows that the specified search strategy yielded 33 citations from two bibliographic databases. After excluding duplicate papers, 23 records underwent title/abstract screening, and five were removed as irrelevant to the topic of focus. Subsequently, the author retrieved the full text of 13 papers for additional assessment against the inclusion and exclusion criteria. Finally, eight citations were removed because they did not meet the inclusion requirements, leaving just five publications for the rapid narrative review.

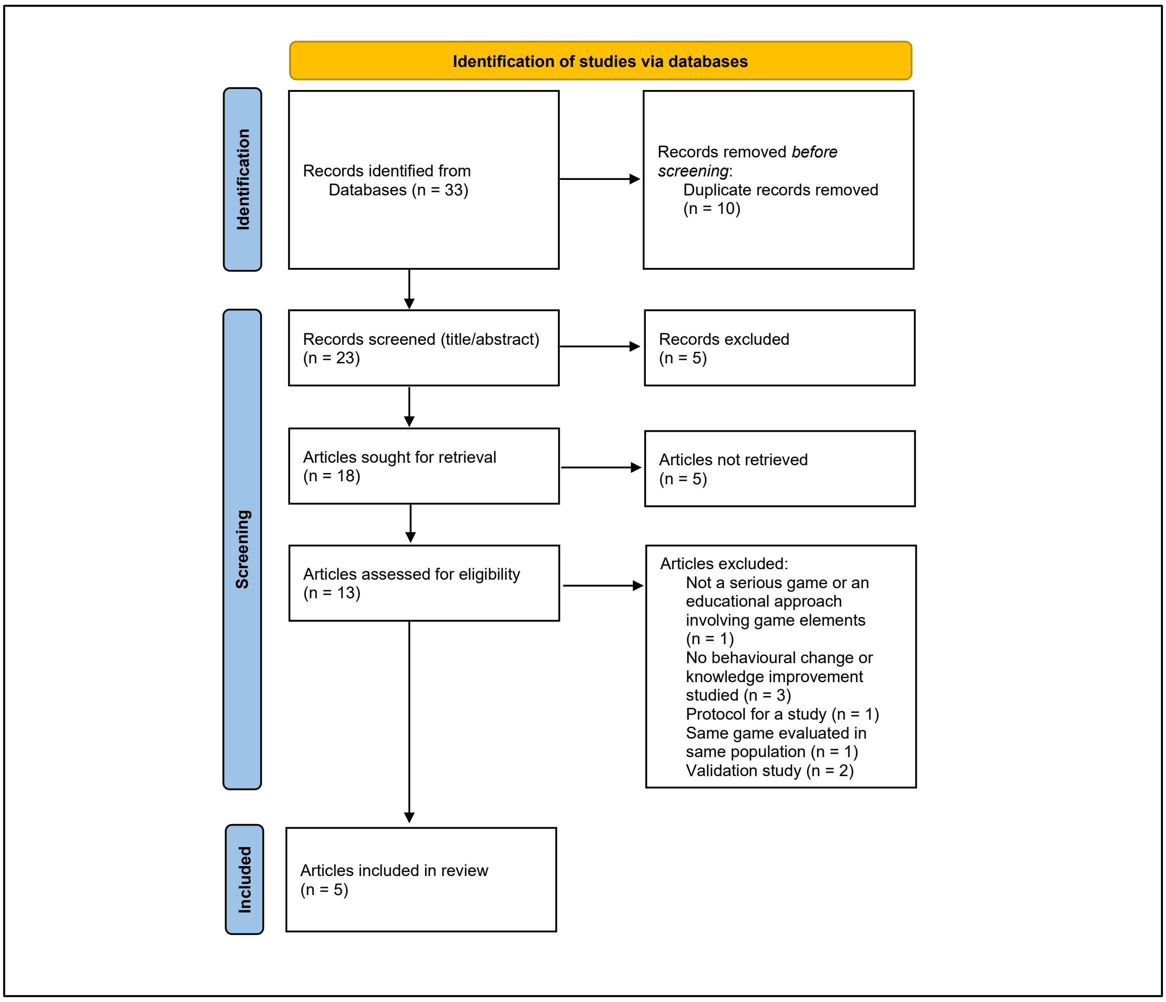

FIGURE 5. PRISMA 2020 flow diagram. Adapted from Page, McKenzie, et al. (2021)

3.2 Study Characteristics and Quality

Table 2 (APPENDIX 2) presents details of study characteristics. All studies were in English and published from 2014 to 2018. The included studies were conducted in the United States (n=2), Canada (n=1), Finland (n=1), and China (n=1). Two studies were randomized controlled trials, 2 were cohort studies, and 1 study was a crossover study. Studies were conducted at the research laboratory, streetside, school, and community center. The target populations of the studies were children, with one study also including adults as a comparison group (Lehtonen et al., 2017). Sample sizes ranged from 44 to 231. All studies included both women and men.

Only 2 out of 4 studies that reported race and ethnicity included a mixture of races and ethnicities (Schwebel et al., 2014, 2016). Only two studies reported the educational level of participants (Lehtonen et al., 2017; Schwebel et al., 2018). Using Quality Assessment Tool for Quantitative Studies (Thomas et al., 2004), the author rated the quality of most studies as 'Strong' (see APPENDIX 3 for details).

3.3 Intervention Characteristics

Table 3 (APPENDIX 2) presents details on intervention characteristics. All games were digital games. Schwebel et al. (2014, 2016) reported on the same game in different populations. Most studies used virtual reality (VR) systems as serious game interventions; only 1 used a touchscreen-based PC game. Most serious games were aimed to improve child pedestrians' street crossing skills (n=4), whereas one aimed to improve child bicyclists' situation awareness. Four studies implicitly reported the theoretical basis of their serious games, which was primarily based on the theory that repetitive practice will improve complex cognitive-perceptual safety skills. Three studies had participants play the games multiple times, while participants in the two studies played the games only once for a range of 20 minutes to 1.5 hours. One serious game was assessed alongside co-interventions (Schwebel et al., 2014).

3.4 Effects on Road Safety-related Outcomes

Table 4 (APPENDIX 2) presents the results regarding effects on road safety-related outcomes.

3.4.1 Effects on Pedestrian Safety Skills

Four studies aimed to improve pedestrian safety skills of participants, in particular road-crossing skills. Three studies conducted by Schwebel et al. (2014, 2016, 2018) used similar outcome measures.

First, 'hits/close misses,' which is a count of possibly unsafe crossings - the child would have been struck by a vehicle if the crossing had been actual rather than simulated or would have been within 1 second of being hit by a vehicle. The outcome measure is included as a gross measure of pedestrian safety (Schwebel et al., 2014). In other studies by Schwebel et al. (2016, 2018), 'percentage of unsafe crossings,' probability of collisions with a vehicle,' and 'time to contact' (the shortest time (measured in seconds) between an approaching vehicle and the location of a child pedestrian at any point during the crossing) was used instead as gross measures.

Second, 'attention to traffic,' which is calculated by dividing the total number of looks to the left and right while waiting to cross the street by the waiting time in minutes. The outcome measure serves as an indicator of the pedestrian's awareness of the traffic environment (Schwebel et al., 2014, 2016).

Last, 'start delay,' which is defined as the temporal gap before the start of the crossing. It is calculated as the time interval in seconds between the emergence of a safe traffic gap (i.e., the last vehicle leaving the crosswalk) and the child stepping down to enter the road. The outcome measure assesses children's cognitive processing efficiency in pedestrian settings (Schwebel et al., 2014, 2016, 2018).

One study reported no significant change in hit/close calls after training using the virtual reality system (Schwebel et al., 2014). On the other hand, participants in two studies displayed a reduction in the average percentage of unsafe crossings, probability of collisions with a vehicle, and time to contact post-intervention with the serious game (Schwebel et al., 2016, 2018). In addition, three studies reported a decrease in start delay post-intervention (Schwebel et al., 2014, 2016, 2018).

Two studies documented an increase in attention to traffic post-intervention when assessed using a VR system (Schwebel et al., 2014, 2016). However, there was a mixed result when assessed in the streetside setting. A randomized clinical trial reported that participants trained using a VR system showed the least attention to traffic compared to other groups in the study during the streetside assessment (Schwebel et al., 2014). In contrast, a cohort study reported improved attention to actual traffic among the participants after VR system training (Schwebel et al., 2018).

The study conducted by Morrongiello et al. (2018) utilized different outcome measures to assess improvement in participants' capability to know appropriate spots crossing spots (termed as 'where to cross' in the study) and performance in desired safety behaviors (termed as 'how to cross' in the study). To measure whether participants know safe crossing spots, they were presented with difficult situations (crossing when there are cars parked on far and near sides of the road, crossing at a blind curve and crossing at the crest of a hill). Participants in the intervention group showed statistically significant fewer errors across all scenarios than the control group (Morrongiello et al., 2018). In addition, children in the intervention group also committed less number of errors compared to the control group (statistically significant) when measured to perform the expected safety behaviors (stop at the curb and make visual safety checks before entering the road) (Morrongiello et al., 2018).

3.4.2 Effects on Bicyclist Safety Skills

One study assessed the effect of a touchscreen-based educational game on child bicyclists' situational awareness (Lehtonen et al., 2017). Unfortunately, the study documented that the participants did not significantly improve situational awareness after the training session. Therefore, it was not possible to conclude that the learning game would be an effective method to teach child bicyclists hazard perception and situational awareness (Lehtonen et al., 2017).

3.5 Categorization of Serious Games

Table 5 (APPENDIX 1) presents the categorization of serious games used in the included studies. There are four unique serious games found in the included studies, as two studies (Schwebel et al., 2014, 2016) utilized the same virtual reality environment validated in an earlier study (Schwebel et al., 2018).

3.5.1 Game Development

Only two studies reported the group responsible for the game development. One game was developed by a private company (Schwebel et al., 2018), while another was developed by a university (Lehtonen et al., 2017). However, none of the studies specified the development methodology.

3.5.2 Game Platform

All of the games were developed to run on PC, except one which was designed as a smartphone application. All games were installed locally on the devices used.

3.5.3 Game Design

All serious games studied were classified as educational simulation games. None of the serious games included a narrative (usually defined as the 'voice of the story that accompanies a video game' (De Lope & Medina-Medina, 2017)). One game utilized a simulated curb as a peripheral for players to interact with the game (Schwebel et al., 2014, 2016). Players would stand on the curb at the start of the game and step down from the curb to indicate that they were ready to cross the road in the game. There were two VR games where the players needed to use a head-mounted display; players either used a lever or a video game controller to perform actions within the games (Morrongiello et al., 2018; Schwebel et al., 2018). None of the studies described the context of use as defined by De Lope & Medina-Medina (2017).

3.5.4 Game Use

Three studies assessed participants through automatic implicit assessment methods pre- and post-gaming sessions, whereas two studies also used manual and explicit assessment methods. Most of the studies did not explicitly assess participants' level of satisfaction and motivation while playing the games. One game provided players with not only visual stimulation but also auditory stimulation, positive verbal reinforcement of desired actions within the game, and live feedback on wrong actions (Morrongiello et al., 2018). Two serious games had adaptive features where the difficulty level of the games would progressively increase throughout the gameplay.

3.5.5 Game Users

All games were described as mono-player. None of the studies categorized players based on their gaming skills.

3.5.6 Business Model

None of the studies specified the license types of the games.

4 DISCUSSION

4.1 Effects on Road Safety-related Outcomes

This narrative review aimed to gain insight into the categorization and effects of serious games on road safety-related outcomes in children. The evidence from several studies suggests that games may positively affect road safety-related outcomes, particularly on road crossing skills. Four studies on pedestrian safety skills assessed 22 unique outcome measures and consistently found positive effects for 21 outcome measures. However, the two studies that included assessment on the streetside setting produced different results regarding the safety performance of participants post-intervention. One study showed decreased attention to the actual traffic in the group trained using the VR system (Schwebel et al., 2014). On the other hand, the other reported increased attention after VR training (Schwebel et al., 2018). A research question inferred from the mixed results is whether the positive impact on road safety skills gained from serious game training can be translated into desired outcomes in a real-life setting.

Some suggestions can be made to improve study design for research involving serious games for children's road safety education. First, as alluded to above, there is a need to incorporate streetside/field-based assessment on top of laboratory-based assessment to validate the real-life impacts of training involving serious games. Although laboratory-based assessments, especially those involving virtual reality systems, have been previously validated for road safety skills assessment (Schwebel et al., 2008), they are still somewhat controlled and unable to fully mimic the complexity and unpredictability of the actual road conditions. Second, researchers should aim to conduct randomized controlled studies whenever appropriate and ethical, as the design includes methodologies that decrease the possibility of bias (randomization and blinding) (Bares, n.d.). Last, only one study compares serious game training intervention to other road safety educational approaches. More studies comparing different educational approaches to serious games are required to justify the cost-effectiveness of the serious game approach.

This review also offers a few areas for further improvements in serious game research in pediatric road safety education. First, none of the included studies were conducted in low- and middle-income countries where the rates of injuries and fatalities resulting from road traffic injuries are higher than those in high-income countries (World Health Organization, 2008). This observation echoes the finding of the Cochrane Injuries Group (Perel et al., 2007). The group re-examined 13 systematic reviews on road safety interventions published by the group and found that out of 236 included studies, only six (2.5%) trials were conducted in low- and middle-income countries (Perel et al., 2007). Furthermore, most interventions targeted vehicle drivers from high-income countries, although most victims are more vulnerable non-drivers from low- and middle-income countries (Perel et al., 2007). This finding shows a possible misallocation of global resources (including funds) for road safety research in low- and middle-income countries. There is an urgent need for relevant authorities to shift the focus and priority to targeting the most common and vulnerable victims of road traffic accidents. Second, the author did not find studies targeting safety skills in children as passengers of motor vehicles. Last, included studies related to pedestrian safety skills only target road crossing skills.

There are other scenarios where child pedestrians might be involved in road traffic injuries, such as playing on the streetside.

4.2 Serious Game Categorization and Development

All serious games used in the included studies can be categorized as simulation games. Four studies took a step further by incorporating virtual reality systems to increase the ‘realism’ of the games. Simulation games offer users a highly accurate experience immediately relevant to the 'real world'(Cheng et al., 2007). Additionally, simulation training provides users with the chance to repeatedly practice in a risk-free environment, allowing for errors and jumping to a conclusion, the capability for researchers and educators to present complicated, potentially dangerous circumstances, and the ability to incorporate and evaluate novel intervention strategies (Cheng et al., 2007).

This review also gives insights on how researchers can better develop the serious games used in road safety education. As documented above, none of the included studies document the game development methodology used. Hence, the author cannot tell whether the games were developed using sets of techniques or procedures specific to serious games, such as the methodology based on Westera levels (Westera et al., 2008). The methodology divides serious game development into three levels; conceptual level, technical level, and practical level (Westera et al., 2008). At the conceptual level, game developers should explore the game dynamics; that is, how various game elements undergo state change over time. For example, how the avatar in the game should move based on the players’ actions. At the technical level, game developers work on the basic system architecture using various building tools, such as object evolution, scenario, and role builders. Last, at the practical level, the game developers should adhere to design principles to control and reduce game design complexity. For example, performance feedback should target the overall players’ progress and performance, not for every single action and decision (Westera et al., 2008).

There are ten game features generally accepted as ’ingredients of great games’: ”self-representation with avatars; three-dimensional environments; narrative context; feedback; reputations, ranks, and levels; marketplaces and economies; competition under rules that are explicit and enforced; teams; parallel communication systems that can be easily configured; time pressure” (Laforcade & Vakhrina, 2016). Three out of four unique games analyzed utilized in-game avatars to help participants identify themselves with the characters they controlled. The same set of games also used three-dimensional environments, which are the standard feature of virtual reality systems. However, none of the games include crucial ’ingredients of great games’ relevant to road safety education, which are narrative context and team-based gaming (Laforcade & Vakhrina, 2016). A narrative context may help to enhance the playability of the games. Meanwhile, team-based gaming or the option to play the game in the multiplayer mode may address social factors, such as peer pressure, identified as contributing factors to road safety injuries (World Health Organization, 2008). Furthermore, only one game provided explicit in-game positive and negative feedback on players’ actions. Explicit feedback is important to help learners clearly understand the impacts of their decisions. Future researchers and serious game developers should consider and implement the ’ingredients of great games.’

There are other areas for improvement that can be deduced from the result of the study. First, none of the included studies reported baseline measurement of gaming skills of the participants, which may contribute effectiveness of the serious game approach. Second, researchers in the included studies did not measure the participants' level of satisfaction and motivation when playing serious games. Satisfaction and motivation are two essential elements that describe users' experiences (De Lope & Medina-Medina, 2017). Understanding users' experiences might be vital in developing serious games that are not only educational but also entertaining.

4.3 Future Applications and Developments

For road safety education in children, field training remains to be the 'gold standard', as there are proven effectiveness of the method (Morrongiello et al., 2018). However, the educational approach can be potentially difficult to implement (e.g., training needs to be delayed due to poor weather conditions), resource-draining (e.g., trainers can only educate a few children at the same time), and the instructor must keep participants safe and avoid dangerous traffic conditions, although the children need to learn these risky situations (Morrongiello et al., 2018). Previously serious games training, especially those designed as virtual reality simulation games, has been identified as a potential replacement that requires fewer resources and can potentially be implemented in resource-constraint low- and middle-income countries. However, the review has shown that the method still requires further investigation to prove its effectiveness before researchers and educators can justify it for funding by government bodies and greater distribution and implementation. Nevertheless, there is still merit to implementing the idea for the commercial educational game market, as the global market size is expected to reach USD 32.6 billion by 2027 (Yahoo!Life, n.d.).

Recent renewed interest in the metaverse may also open possibilities for new technologies to enhance the serious game approaches. Metaverse can be defined as "a 3D-based virtual reality in which daily activities and economic life are conducted through avatars representing the real themselves" (Kye et al., 2021). Other than virtual reality systems, there are three other types of metaverse: augmented reality, lifelogging, and mirror world (Kye et al., 2021). Augmented reality refers to a form of technology that augments the real physical world utilizing location-based technologies and networks (Kye et al., 2021). A popular example of the application of technology is Pokemon Go. Lifelogging refers to the internet of things technology that captures, stores, and shares the daily lives of users, such as wearable devices (Kye et al., 2021). Last, the mirror world refers to virtual maps and models that reflect the real world and provide integrated environment information (Kye et al., 2021). Of the different types of the metaverse, augmented reality combined with lifelogging devices can be explored for novel serious game approaches.

4.4 'Ideal' Serious Game for Road Safety Education

Guided by the serious game taxonomy by De Lope & Medina-Medina (2017), quality standards as specified in the Quality Assessment Tool for Quantitative Studies (Thomas et al., 2004), best practices in game design such as '10 ingredients for great games' (Laforcade & Vakhrina, 2016), and digital health principles, the author attempts to 're-imagine' an ideal serious game study and development for road safety education in children. The author will design the study to target child pedestrians since there is evidence of positive effects on road safety skills for the group, as observed from the review.

4.4.1 Proposed Study Design

For the recruitment of participants, the author will randomly select participants from schools and community centers to ensure the selected participants are likely to represent the target population and reduce selection bias. The author will also need to achieve 100% informed consent from participants and their parents (as most likely the participants are minors) to participate in the study.

The author will use the randomized controlled trial model as the study design. The model dictates the investigator to randomly allocate eligible participants to intervention or control groups, reducing the probability of bias due to the allocation process (Thomas et al., 2004). The author will use the appropriate randomization method, such as alternation, and ensure each study participant has the same chance to be allocated to either the intervention or control group.

As the participants would be allocated randomly, the author will also report that the groups have similar confounders at baseline to reduce the impacts of relevant variables' impacts on the outcomes of interest. Apart from collecting the usual participants' characteristics such as sex, age, ethnicity/race, and educational level, the author will also collect possible confounders specific to serious game intervention, such as technology literacy and baseline gaming skills.

The author will mimic the study design by Schwebel et al. (2014) to include three intervention groups and one control group. Apart from the group trained in serious gaming, other intervention groups would undergo streetside training (the so-called 'gold standard' intervention) and classroom training (more common 'traditional' intervention), respectively. The control group will not receive any training. Such design may help answer whether serious game intervention is at least non-inferior to streetside training and superior to classroom training and no training.

4.4.2 Proposed Serious Game Design

Virtual reality technology offers users the opportunity to experience simulated situations in a controlled environment that is not easily replicated in real life. However, with road safety, virtual reality may not address the perceptual-motor skills necessary to react promptly to traffic situations and perform the necessary motoric actions (Willyarto et al., 2019). Furthermore, although virtual reality offers an immersive experience, the virtual environment will not be able to mimic the real-life environment fully. Furthermore, virtual reality users may need to adapt and translate the skills learned in the serious game when faced with real-life situations. Hence, the author opts to use augmented reality combined with a physical 'road safety park,' sensor technology, and wearables.

The serious game will be played at a road safety park that is designed to mimic the real-life road environment minus the actual vehicles. Ideally, the park should include essential features such as pedestrian walkways, traffic lights, zebra crossing, and traffic signs. The park should also be designed to include areas where risky situations may occur, such as blind curves and the crest of the hill.

Instead of using heavy head-mounted virtual reality displays, participants will be equipped with lighter smart glass (e.g., Google Glass). The smart glass will enable participants to see virtual projections appearing on the in-built liquid crystal on silicon display. In addition, location sensors placed in various spots within the park are interfaced with the smart glass and enable the smart glass to display the appropriate moving images depending on the user's location. Users will also be equipped with a smart watch that serves as a tool to measure users' vital signs, such as heart rate, and a device to provide visual and haptic feedback and store patients' progress.

The general idea for the game is for the user to see virtual vehicles roaming around the road sections of the park through the smart glass. The park will be divided into several 'stations'. Users will need to complete specific tasks at each station and learn a particular lesson about road safety. For example, when a user approaches the zebra crossing section, the smart watch will provide information on recommended safety checks and give the task to the user to cross the road safely. Whenever the user does not heed the safety instruction (for example, the user crosses the road when the oncoming vehicle has not entirely come to a stop), the smart watch will provide haptic feedback (to give a 'motoric' warning) and educate the user on how to improve his/her performance.

The author considers how to improve users' satisfaction and motivation while playing the game. By establishing a reasonable learning curve, users' satisfaction may be achieved (De Lope & Medina-Medina, 2017). Users may be guided to complete more manageable tasks before being suggested to attempt more complex tasks. The tasks and challenges should be designed to be achievable but not too simple to motivate users to play the educational game (De Lope & Medina-Medina, 2017). The author will also consider implementing a ranking system and competition mode to provide further motivation.

It is also advisable to include a simple narrative context for the overall game. For example, users are told to complete tasks safely under time pressure because they will be late for school. The narrative context will help users relate what they have learned with daily life situations through the game. Implementation of a narrative context will also allow the possibility of incorporating cartoon characters into the game to increase users' motivation and the fun level of the game.

Overall, the proposed game design may help participants become more familiar with the real-life roadside environment and physical safety features implemented. This approach may reduce users' need to adjust their perceptions when moving from the virtual training environment to the actual street condition. Not only that, but the safety park also allows them to practice their perceptual-motor skills. At the same time, augmented reality removes the safety hazards that may arise with streetside training, providing a safe learning environment. The smart watch will also reduce the need for constant instruction from streetside trainers.

4.4.3 Proposed Serious Game Development

The author proposes that the game be developed in collaboration with a research institution and a serious game developer company. Research institutions, such as universities can provide expertise on the proper study design, ethics approval, and statistic consideration to determine the impact of the intervention on outcomes of interest. A serious game developer company is preferred over a usual video game company as there are specific sets of methodology for developing the serious game, as mentioned above.

On top of using the appropriate development methodology, it is also essential to ensure the game is usable and has an easy user interface. There has been an emphasis on usability in the digital health field. Solution developers are advised to consider learnability (how easy for first-time users to complete basic tasks), efficiency (how fast users can perform tasks), memorability (how easily can users remember how to complete the tasks), errors (including count, severity, and whether it is possible to recover from errors), and satisfaction (pleasantness of the design) (Nielsen, 2012). It is then recommended for the game developer to conduct user testing during the game's development process (Nielsen, 2012).

It would not be easy to find funding sources for the proposed game, especially in low- and middle-income countries. One possible way to obtain sufficient funds is to work together with theme park developers. The proposed game can not only serve as an educational tool for children but also a potential educative and interactive playground. There have been examples of road safety parks worldwide, such as the Road Safety Community Park in Singapore. After the research study has been completed, the park can be repurposed as a recreational park and a possible school excursion destination.

4.4.4 Proposed Outcome Measure

For the proposed study, there are two categories of outcome measures. The first category is for outcome measures that are related to road safety skills improvement. While it is possible to conduct the pre- and post-intervention assessments in a laboratory setting (e.g., using a virtual reality system), it is preferable to conduct the assessments at the streetside, as emphasized above. Streetside assessment will give a more accurate estimate of children’s actual road safety skills than laboratory-based assessment. On top of that, participants who are trained in the serious game may become more familiar with the technology used and have their performances in the laboratory somewhat positively impacted (Schwebel et al., 2014).

The second category for outcome measure is serious game-related. In particular, two areas can be measured, as mentioned previously. The first measure is satisfaction. This attribute can be measured by analyzing emotions throughout the gameplay (e.g., through heart rate), determining the number of attempts required to complete each challenge and the time taken to complete each task (De Lope & Medina-Medina, 2017). The second measure is motivation, which can be measured by the percentage of successfully completed and incompleted tasks (De Lope & Medina-Medina, 2017). Again, these measures can be automatically performed through the smart watch in the proposed game design.

It is important for assessors to be blinded to which participants are in the control and intervention groups for outcome measurement and analysis to reduce detection bias (Thomas et al., 2004). To prevent reporting bias, study participants should also also be blinded to the research questions (Thomas et al., 2004).

4.5 Limitation

There are several significant limitations to this review. First, this review only included small numbers of studies, hence decreasing the generalizability of the review's conclusions. Second, the author did not involve other reviewers in the inclusions process of identified studies and quality appraisal of included studies. Hence, there was room for subjectivity in these processes. Last, the author is dependent on the descriptions of games in the included studies for the classification of serious games, which were often not detailed. Therefore, the author might have misclassified the games.

4.6 Ethics of the Study

The author is committed to adhering to the ethical recommendations for thesis writing and responsible conduct of research as specified by Savonia University of Applied Sciences. Furthermore, the author has done due diligence to avoid plagiarism and cite others' works and ideas. The author has also adhered to the Copyright Act by attributing the source references to direct quotations and following the terms and conditions specified in copyright licenses (e.g., Common Creative licenses). Last, research permission is not required as the study does not disclose information on Savonia UAS or its students or staff or involve participants. The author has obtained relevant permission from the thesis supervisors.

The author also considered the ethical guiding principles in conducting systematic reviews proposed by Suri (2019). The first guiding principle is ”informed subjectivity and reflexivity,” where reviewers should adhere to the appropriate ethical considerations depending on the ”epistemological orientation” used (Suri, 2019). The author used an interpretive approach for the review, as he aims to present a comprehensive understanding of the road safety serious game phenomena. Teleological ethics is applicable in such a review, where the reviewer should consider studies conducted in diverse groups in varied contexts (Suri, 2019). The author has done so by not limiting the country where the study was conducted and the research setting in the literature search and inclusion process.

The second guiding principle is ”purposefully informed selective inclusivity,” where reviewers must extract information from included studies that are most relevant to achieving the objectives of synthesis (Suri, 2019). The author has described the relevancy of the extracted information in section 2 (Material and Methods) of the review. Sections 3 (Results) and 4 (Discussions) also prove that the review's objectives have been achieved due to the selected retrieved data. The same sections mentioned above also showed that the author adhered to the last guiding principle,” audience-appropriate transparency” (Suri, 2019). The literature retrieval, inclusion, and analysis methods have been described clearly.

To assess the review's validity, the author used questions proposed by Thompson et al. (2012). First, has the author performed a comprehensive literature search? Unfortunately, the author did not include a comprehensive search in all relevant major bibliographic databases and inquire about unpublished studies due to the limited time availability. However, the author used both MESH terms and text words in the search criteria. Second, has the author selected and described appropriate criteria for article inclusions? The author has done so as described in section 2.2. Third, are the included studies sufficiently valid to answer the research questions? The author has assessed the validity of the studies by reporting the quality of each study and the appraisal tool used. Last, are the results and outcomes similar from study to study? The author has reported the outcome measures used by included studies, which unfortunately are not homogeneous. Moving forward, the author can aim to improve the review's validity by performing a more comprehensive literature search.

To assess the review's reliability, the author used the standards set by Haddaway et al. (2015). In general, the review is quite reliable. The author clearly defined the research questions and described the search strategy. The author also developed an appropriate and comprehensive search string. Last, the author consistently used the same inclusion criteria, quality appraisal tool, and information extraction and analysis methods for all identified studies. However, there are some areas for improvement. Similar to the issue identified in assessing the review's validity, there is a need to expand the literature search scope. The author should also attempt to conduct a weighted quantitative synthesis of the study outcomes in the future, although this process may be hindered by a lack of standardized outcome measures as identified in included studies.

4.7 Learning Points

The author has decided to use the rapid narrative review method due to the time available to conduct and write the thesis. If time permits and there are additional members to the research group, the author may select the systematic review methodology instead. The systematic review process requires more than one reviewer to conduct the literature search, study inclusion, quality appraisal, and analysis of results to reduce subjectivity (Deaver, 2022). In a systematic review, reviewers will search all relevant published and unpublished studies to minimize subjective selection bias and perform a meta-analysis to produce a pooled estimate of intervention effectiveness (Deaver, 2022). The systematic review approach may improve the overall validity and reliability of the thesis. However, it might be challenging to generate a pooled estimate of intervention effectiveness as different road safety studies do not use standardized outcome measures, as shown in this review. Hence, in hindsight, the narrative review methodology, which includes qualitative analysis, may better suit the research questions.

The author has also used the thesis development process to learn project management skills, including resource and time allocation skills. It is not easy to write a thesis in a field that is not directly connected to the author's profession. Hence, a significant amount of time is required to learn the basics of road safety education and serious game research. Fortunately, the knowledge acquired throughout the master's program at Savonia University of Applied Sciences has helped the author to adapt and acquire new skills quickly.

5 CONCLUSION

In 1981, a popular arcade game entitled *Frogger* (Konami Holdings Corporation, Japan) was released in Japan and became an instant hit worldwide. In the game, players are tasked to control a frog to cross dangerous roads full of oncoming vehicles. While the game is highly entertaining, it is certain that gamers should not mimic such dangerous behaviors displayed by the frog. Hence, the author playfully included a reference to the game in the title of this review.

Fortunately, despite the unintentional 'failure' of *Frogger* to educate children in road safety skills, this review has shown insight into the categorization and positive effects of serious games on road safety-related outcomes. The review has also revealed a few research questions that need to be addressed by researchers, educators, serious game developers, and decision-makers in the field.

First, is it possible for a collective group of researchers to develop a standardized set of validated outcome measures for children's road safety education to enable a pooled estimate of serious game intervention effectiveness? Second, how to help children translate the knowledge and skills gained through the serious game into real-life settings? Third, how can researchers and game developers better utilize the best practices and principles in serious game design and development to further improve its effectiveness? Fourth, which technology is best to be used for a serious game? Last, can serious game intervention be a promising educational approach in low- and middle-income countries, and how to fund its research and development? The author has provided a proposed 'ideal' serious game design and study approach that may serve as inspiration for others.

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APPENDIX 1

Table 1. Serious Game Taxonomy by De Lope & Medina-Medina (2017)

Category	Taxonomy Criteria	Description
Game development	Authorship	Specifies the author or group involved in the game development
	Develop methodology	Documentation of techniques or methodology used during the game development
Game platform	Hardware architecture	The hardware components used to run the games
	Deployment	Which environment is the game is run and installed (e.g., local or Web)
Game design	Genre	Classification of games based on gameplay
	Narrative	”Voice of the story” embedded in the video game
	Interactivity	The user interface used by the game
	Context of use	Documentation of various external and internal factors that may affect the objectives of the serious game
Game use	Application area	The domain for which the game is developed
	Assessment	How the authors evaluate the game’s effectiveness concerning its objectives
	Gameplay	Elements and attributes of the game that can be used to classify a game
	Adaptation	Whether the game has features to adapt to player capabilities and characteristics
Game users	Target audience	The group for which the game is developed and the rating given by classification authorities (e.g., Entertainment Software Rating Board)
	Player interaction	Whether the game can be played by single-player or multiplayer
	Dedication	Time required by users to familiarise and master the game
Business model	License	License type specified by the author(s)

APPENDIX 2

Table 2. Study characteristics

Study	Quality Assessment[a]	Country	Design	Setting
Schwebel 2014	Strong	United States	Randomized controlled trial	Laboratory A field in front of a crosswalk on a two-lane bi-directional road
Schwebel 2016	Strong	United States	Cohort study	Laboratory Schools Community centers
Schwebel 2018	Strong	China	Cohort study	Streetside School
Morrongiello 2018	Strong	Canada	Randomized Controlled Trial	Research lab
Lehtonen 2017	Weak	Finland	Crossover/switching replications design	Laboratory Schools

(continued)

Table 2. continued

Study	Participants	Sex	Age (year)	Ethnicity/race	Educational Level
Schwebel 2014	Children recruited from community sources (n = 231)	Male 43% Female 57%	VR group: 7.9 (0.67) Streetside group: 7.9 (0.68) Video group: 8.1 (0.63) Control group: 8.1 (0.63)	VR group: White 59%, African American 39%, Other/Biracial 2% Streetside group: White 53%, African American 39%, Other/Biracial 9% Video group: White 53%, African American 40%, Other/Biracial 7% Control group: White 47%, African American 43%, Other/Biracial 10%	NR
Schwebel 2016	Children recruited from two elementary schools and a youth center (n = 44)	Male 49% Female 51%	8.01 (0.56), 6.8–9.0	Caucasian 48%, African American 58%,	NR
Schwebel 2018	Children recruited from an urban primary school (n = 56)	Male 55.4% Female 44.6%	9.3 (0.3), 8.3-10.1	Han Chinese 89.3%, Not specified 10.7%	4th grade primary school

(continued)

Table 2. continued

Study	Participants	Sex	Age (year)	Ethnicity/race	Educational Level
Morrongiello 2018	Children recruited throughout the local community (n=130)	Intervention group for where to cross: Male 48% Control group for where to cross: Male 45% Intervention group for how to cross: Male 53% Control group for how to cross: Male 52%	Intervention group for where to cross: 8.90 Control group for where to cross: 8.92 Intervention group for how to cross: 8.59 Control group for how to cross: 8.70	Intervention group for where to cross: Caucasian 95% Control group for where to cross: Caucasian 96% Intervention group for how to cross: Caucasian 98% Control group for how to cross: Caucasian 100%	NR
Lehtonen 2017	Children from the 2nd grade of primary school (n = 39) University students (n = 31)	Children group: Male 55.10%; Female 44.90% Adult group: Male 29%; Female 71%	Children group: 8 Adult group: 22-34	NR	Child group: 2nd grade primary school Adult group: University student

Values are mean; range; mean (SD), range; or mean (SD) unless otherwise indicated.

NR: not reported.

[a] See APPENDIX 2 for detail.

Table 3. Intervention characteristics

Study ID	Objective	Serious Game Intervention	Type	Theoretical Basis	Intervention Group(s)	Game Play	Control Group(s)
Schwebel 2014	Improvement in pedestrian safety skills	An immersive, interactive virtual pedestrian environment	Digital	Repetitive practice for the cognitive, perceptual, and motoric aspects of pedestrian behavior	1. Training in a virtual pedestrian environment 2. Individualized streetside training 3. Training using videos and websites	Six sessions, a total of 45 virtual crossings per session	No training
Schwebel 2016	Improvement in pedestrian safety skills	A mobile virtual environment	Digital	Individualized repeated practice targeting complex cognitive-perceptual skills	1. Training in the mobile virtual environment	Twice per week (15 mean each, consisting of 25 crossings), for three weeks (total of six sessions)	Not applicable
Schwebel 2018	Increase in self-efficacy for street-crossing	Smartphone-based virtual reality system	Digital	Repeated practice in the complex task (”domain-specific learning”) to accelerate learning of cognitive-perceptual skills	1. Training using smartphone-based VR	12 training sessions consisting of four sets of street-crossing (each set lasted 4 min or 12 crosses)	Not applicable

(continued)

Table 3. continued

Study ID	Objective	Serious Game Intervention	Type	Theoretical Basis	Intervention Group(s)	Game Play	Control Group(s)
Morrongiello 2018	Improve children's skills regarding when and how to cross a street safely	A virtual reality system consisting of a PC, VR headset, and game controller	Digital	Detailed feedback, repeated practice, and progressively complex practice experience	1. Where to cross training module utilizing the VR system 2. How to cross training module utilizing the VR system	One training session lasted 1-1.5 hours, divided into four stages	1. Control group for where to cross 2. Control group for how to cross Note: Both controls group did not undergo training but still played a VR-based non-serious game
Lehtonen 2017	Improve child bicyclists' situation awareness	Touchscreen-based PC learning game	Digital	Not specified	Half of the participants played the game after the first Situational Awareness test; the other half played the game after the second test. In total, there were three rounds of the Situational Awareness test.	One learning session of approximately 20 min	Not applicable

Table 4. Effects on road safety-related outcomes

Study ID	Measures	Outcomes	Direction of Difference	Statistical Significance
Schwebel 2014	Field assessment 1. Hit/Close Calls (count over 16 trials) 2. Attention to Traffic (looks/wait time) 3. Start Delay (seconds) VR assessment 4. Hit/Close calls (count over 30 trials) 5. Attention to Traffic (looks/wait time) 6. Start Delay (seconds) 7. Missed Opportunities (count over 30 trials)	1. The VR group showed a modest increase in the mean count of hits/close calls postintervention. The outcome is similar across all four groups. 2. Post-intervention, the VR group showed the least mean attention to traffic compared to other groups. 3. Post-intervention, the VR group showed the sharpest decrease in the mean time for start delays, while the streetside group showed a sharp increase in the same measure. 4. Both streetside and VR groups showed a modest decrease in the mean count of hits/close calls, while the control groups showed a significant increase in risky crossing. 5. Post-intervention, the VR group showed the sharpest increase in attention to traffic. 6. The VR group showed the sharpest decrease in the mean timing for start delays compared to other groups. 7. Post-intervention, the VR group showed a sharp decrease in the mean count of missed opportunities, while the streetside group showed a significant increase in the same measure.	1. Increase 2. Decrease 3. Increase 4. Decrease 5. Increase 6. Decrease 7. Decrease	1. Not significant 2. Not significant 3. Significant 4. Not significant 5. Not significant 6. Significant 7. Significant

(continued)

Table 4. continued

Study ID	Measures	Outcomes	Direction of Difference	Statistical Significance
Schwebel 2016	1. Attention to traffic (looks/wait time in second) 2. Start delay (seconds) 3. Time to contact (seconds) 4. Unsafe crossings (percentage)	1. Participants' average attention to traffic reduced from 0.51 (0.18) looks/second to 0.46 (0.20) looks/second at post-intervention. 2. Post-intervention, participants' average start delay slightly dropped from 1.24 (0.50) seconds to 0.96 (0.50) seconds. 3. After training, the average time to contract decreased slightly from 3.37 (1.97) seconds to 3.19 (1.59) seconds. 4. There was no significant drop for average count of unsafe crossing percentage (pre-intervention: 26.49% (12.58); post-intervention: 23.03% (12.47))	1. Decrease 2. Decrease 3. Decrease 4. Decrease	1. NR 2. NR 3. NR 4. NR

(continued)

Table 4. continued

Study ID	Measures	Outcomes	Direction of Difference	Statistical Significance
Schwebel 2018	1. Brief survey to assess participants' self-efficacy about their pedestrian safety VR Assessment 2. Collisions (percentage) 3. Unsafe crossings (percentage) 4. Time to contact (seconds) 5. Start Delay (seconds) 6. Stops in Roadway (count) Streetside Assessment 7. Percentage of following directions from the crossing guard 8. Percentage of looking at oncoming traffic	1. Participants generally perceived themselves as significantly safer and more skilled pedestrians after training. 2. After training, the average probability of collision was reduced from 40% (0.15) to 9% (0.10). 3. Post-intervention, the average probability of unsafe crossings decreased from 84% (0.19) to 47% (0.25). 4. Average time to contact showed a decrease after training. 5. Participants showed a reduced average start delay after training. 6. There was a reduction in the average number of stopping in the roadway mid-crossing from 63% (0.24) to 52% (0.23). 7. Participants followed directions from the crossing guard less frequently post-intervention. 8. Participants looked at oncoming traffic more often after training.	1. Increase 2. Decrease 3. Decrease 4. Decrease 5. Decrease 6. Decrease 7. Decrease 8. Increase	1. Not significant 2. Significant 3. Significant 4. Significant 5. Not significant 6. Not significant 7. Not significant 8. Not significant

(continued)

Table 4. continued

Study ID	Measures	Outcomes	Direction of Difference	Statistical Significance
Morrongiello 2018	Where to cross The number of errors (count) for the following crossing situations: 1. Far side parked cars 2. Near side parked cars 3. Blind curve 4. Crest of the hill How to cross The number of errors (count) for the following desired safety behavior in crossing: 5. Stop at the curb 6. Left check at the curb 7. Right check at the curb 8. Check right parked car 9. Check left parked car	1. Children who received the training made approximately 83% fewer errors than those in the control group. 2. Participants in the training group made 90% fewer errors than those in the control group at post-test. 3. 89% fewer errors occurred in the intervention than in the control group. 4. Participants made 84% fewer errors in the training than the control group. 5. Analysis of error data showed 93% fewer errors at post-test in the intervention compared with the control group. 6. Participants in the training group made 75% fewer errors than those in the control group. 7. Participants in the intervention group made 89% fewer errors at post-test than those in the control group. 8. Children in the training group made 86% fewer errors than those in the control group 9. Participants in the training group made approximately 82% fewer errors of this type at post-test than those in the control group	1. Decrease 2. Decrease 3. Decrease 4. Decrease 5. Decrease 6. Decrease 7. Decrease 8. Decrease 9. Decrease	1. Significant 2. Significant 3. Significant 4. Significant 5. Significant 6. Significant 7. Significant 8. Significant 9. Significant

(continued)

Table 4. continued

Study ID	Measures	Outcomes	Direction of Difference	Statistical Significance
Morrongiello 2018 (cont.)	How to cross The number of errors (count) for the following desired safety behavior in crossing: 10. Look left at the parked car 11. Look right at the parked car	10. Children in the training group committed 96% fewer errors than the control group. 11. Children who received the training made approximately 80% fewer errors than those in the control group.	10. Decrease 11. Decrease	10. Significant 11. Significant
Lehtonen 2017	1. Sensitivity to overt and covert targets 2. Answer latencies (second) 3. Response bias Note: The author only included measures documented for the child group, which is the subject of interest in the review	1. Training using the learning game did not significantly increase sensitivity to targets. 2. The training marginally improved the answer latencies. 3. The training marginally reduced the response bias.	1. Increase 2. Decrease 2. Decrease	1. NR 2. NR 3. NR

Values are mean; range; mean (SD), range; or mean (SD) unless otherwise indicated.

NR: not reported.

Table 5. Serious games and educational approaches are categorized according to the taxonomy of De Lope & Medina-Medina (2017)

Studies	Category	Game Development		Game Platform		Game Design				
	Criteria	Authorship	Development Methodology	Hardware Architecture	Deployment	Genre	Narrative	Interactivity	Context of Use	Application Area
Schwebel 2014[a]		NR	NR	PC	Local	Simulation	None	Simulated curb	NR	Education
Schwebel 2016[a]		NR	NR	PC	Local	Simulation	None	Simulated curb	NR	Education
Schwebel 2018		Digital Artefacts, LLC	NR	Smartphone	Local	Simulation	None	VR stereo viewer and a lever for user input	NR	Education
Morrongiello 2018		NR	NR	PC	Local	Simulation	None	Head-mounted VR display/googles (Oculus Rift) and game controller	NR	Education
Lehtonen 2017		University of Helsinki	NR	PC	Local	Simulation	None	Touch-screen	NR	Education

(continued)

Table 5. continued

Studies	Category Criteria	Game Use			Game Users			Business Model
		Assessment	Gameplay	Adaptation	Target Audience	Player Interaction	Dedication	License
Schwebel 2014		The mix of automatic and manual implicit and explicit assessments pre- and post-gaming session	Visual	None	Child pedestrians	Mono-player	NR	NR
Schwebel 2016		Automatic implicit assessments pre- and post-gaming session	Visual	None	Child pedestrian	Mono-player	NR	NR
Schwebel 2018		The mix of automatic and manual implicit and explicit assessments pre- and post-gaming session	Visual	Progressive difficulty level	Child pedestrian	Mono-player	NR	NR
Morrongiello 2018		Automatic implicit assessments pre- and post-gaming session	Visual, auditory, positive verbal reinforcement, live feedback	Progressive difficulty level	Child pedestrian	Mono-player	NR	NR
Lehtonen 2017		Automatic implicit assessments pre- and post-gaming session	Visual	None	Child bicyclist	Mono-player	NR	NR

[a] The virtual reality environment specified in both studies is based on the environment validated in Schwebel et al. (2008).

NR: not reported.

APPENDIX 3: QUALITY ASSESSMENT FOR INCLUDED STUDIES

Study ID	Component Ratings						Global Rating
	Selection Bias	Study Design	Confounders	Blinding	Data Collection Methods	Withdrawal and Drop-outs	
Schwebel 2014	Strong	Strong	Strong	Moderate	Strong	Strong	Strong
Schwebel 2015	Strong	Moderate	Strong	Moderate	Strong	Strong	Strong
Schwebel 2018	Moderate	Moderate	Moderate	Moderate	Strong	Strong	Strong
Morrongiello 2018	Strong	Strong	Strong	Moderate	Strong	Strong	Strong
Lehtonen 2016	Weak	Weak	Weak	Moderate	Strong	Weak	Weak