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TECHNOLOGY REVIEW (MINI-HTA)

DRIVING SIMULATOR IN HEALTHCARE

Malaysian Health Technology Assessment Section (MaHTAS)
Medical Development Division
Ministry of Health Malaysia
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EXECUTIVE SUMMARY

Background

Driving is a complex activity that requires intact cognitive, behavioural, and motor function. Driving also represents an important activity of daily living as it enables community reintegration, independence and engagement in social, vocational and leisure pursuits. Driving test or driving assessment among people with history of illnesses that altered the cognitive or motor function might be difficult with on-road assessment. However, currently there is a driving simulation technology that able to provide driving test or assessment in safe environment. The simulation technology provides safe, objective and repeatable performance measures pertaining to operational or tactical driver behaviours.

The driving simulator has the potential to serve as a re-training tool that can be designed to provide experiences that apply and challenge specific motor, cognitive, and perceptual skills within a safe, non-confronting and contextual driving environment. The technology of driving simulators evolved over the past decade to make driving simulator systems more appropriate and available for widespread use in clinical settings. Many occupational therapy researchers and other professionals used driving simulators to test a variety of applications across drivers. Some examples include: Alzheimer's, traumatic brain injury, post-traumatic stress disorders, epilepsy, hemianopia, Parkinson's Disease, stroke, attention deficit hyperactivity disorder (ADHD) and autism spectrum disorder. In Malaysia rehabilitation practice - common medical impairments referred for pre-driving assessment are neuro-medical condition such as stroke; musculoskeletal condition such as congenital or acquired limb defects, orthopaedic deformities; neurological condition such as foot drop, spinal cord injury; and neurosurgical cases such as acquired brain injury.

This technology review was requested by an Occupational Therapist, Hospital Tengku Ampuan Afzan (HTAA), Ministry of Health Malaysia in order to expand its usage in Ministry of Health facilities.

Objective/ aim

The objective of this technology review was to assess the efficacy/effectiveness, safety and cost-effectiveness of driving simulator for vehicle driving among patients with/recover from various health conditions such as stroke patients, brain injuries and visual impairment.

Results and conclusions:

Search results

A total of **79** records were identified through the Ovid interface and PubMed. After removal of duplicates and irrelevant titles, **66** titles were found to be potentially relevant and were screened using the inclusion and exclusion criteria. Of these, **58** relevant abstracts were retrieved in full text. Referring to the inclusion and exclusion criteria, **12** studies were included

while **46** studies were excluded since the studies were already included in the systematic review and meta-analysis (n=6), narrative reviews (n=8) and driving simulator was not the main intervention (n=32). **Twelve** full text articles finally selected for this review comprised of five systematic review, two RCTs, three non-RCTs and two cross-sectional studies. The studies were conducted mainly in United States, Canada, United Kingdom, and Germany.

Conclusions

Based on the review, the outcomes of the driving simulator varied depending on types of illnesses, driving simulators specifications, and driving environments.

The retrievable evidence showed that, the driving simulator able to assess the capabilities of the patients in controlling their physical/sensory skills, and cognitive-perceptual while taking turn, break or handling any emergency reactions while driving. It enables the assessor to determine whether the patients can return to drive or not. The driving simulator allowed the patients to practise various driving skills, re-familiarize themselves with the task of driving and prepare for return to on-road driving within a safe environment.

In terms of safety, simulator sickness occurred such as headaches, heaviness in the head, eye-strain and difficulty focusing and dizziness/vertigo due to sharp movements of the screen, increases in environmental stimuli and going around corners. Others were fatigue, nausea, general discomfort and upper limbs soreness due to prolong used of the steering wheels.

There was no study on cost-effectiveness of driving simulator retrieved, however, the price for the driving simulator machine was varied depends on types, brands and specifications.

Methods

Literature search was conducted by an *Information Specialist* who searched for published articles on driving simulator. The following electronic databases were searched through the Ovid interface: Ovid MEDLINE® In-Process & Other Non-Indexed Citations and Ovid MEDLINE® 1946 to September 2021. Parallel searches were run in PubMed, US FDA and INAHTA database. No limits were applied to the search. Additional articles were identified from reviewing the references of retrieved articles. The last search was performed on 23rd September 2021.

TABLE OF CONTENTS

ABBREVIATIONS

VR	Virtual Reality
DS	Driving simulator
NS	Neurophysiological
ADHD	Attention Deficit Hyperactivity Disorder
CDRS	Certified Driving Rehabilitation Specialist
ADHD	Attention Deficit Hyperactivity Disorder
GRS	Global Rating Score
SMS	Sum of Manoeuvre Score

1.0 BACKGROUND

Driving is a complex activity that requires intact cognitive, behavioural, and motor function.[1] Driving also represents an important activity of daily living as it enables community reintegration, independence and engagement in social, vocational and leisure pursuits. There were evidences to support a relationship between driving status, quality of life and psychological outcomes. Therefore, there is a demand for effective treatments to rehabilitate driving skills and facilitate safe return to drive among certain group of people all over the world.[2] One local study among spinal injury patients by Ramakrishna published in 2011, the study found a relatively high return to work rate of 57.7% and overall, 76.2% have worked at some point since injury. The significant positive factors related to employment were being of younger age at the time of injury, independence in personal care, mobility and ability to drive modified vehicle, whereas being hospitalized in the last one year and receiving financial incentives were negatively related to employment after injury.[3]

Driving test or driving assessment among people with history of illnesses that altered the cognitive or motor function might be difficult with on-road assessment. However, currently there is a driving simulation technology that able to provide driving test or assessment in safe environment. Simulation is a tool that requires the identification of training needs, a proper design of scenario, an appropriate performance measurement and feedback and consideration for trainee characteristics, work environment characteristics and the transfer environment.[4] Flight simulators was the first simulators appeared before the second World War and used for training purposes. In the late 50s, highway research simulators were developed and the first actual highway simulator was operated in the early 60s. The simulation technology provides safe, objective and repeatable performance measures pertaining to operational or tactical driver behaviours. Since then, the use of driving simulators increased either for training or research purposes.[5]

The driving simulator has the potential to serve as a re-training tool that can be designed to provide experiences that apply and challenge specific motor, cognitive, and perceptual skills within a safe, non-confronting and contextual driving environment.[6] The simulator also hold key advantages for identifying risks of driving safety among different driver populations and across driving conditions when compared to office-based tools and on-road testing.[7] Driving simulator technology provides a viable mode to assess the fitness to drive skills of at-risk drivers who may not be ready or competent to pursue an on-road assessment. The simulator programmer or operator can control driving environment, modify the degree of risk exposure for the client and expose the client to the variety of driving situations. The technology of driving simulators evolved over the past decade to make driving simulator systems more appropriate and available for widespread use in clinical settings. It evolved to be more capable, less expensive and simpler to operate than the earlier version. Many occupational therapy researchers and other professionals were using driving simulators to test a variety of applications across drivers. Some examples include: Alzheimer's, traumatic brain injury, post-traumatic stress disorders, epilepsy, hemianopia, Parkinson's Disease, stroke, attention deficit hyperactivity disorder (ADHD) and autism spectrum disorder.[8] In Malaysia rehabilitation practice - common medical impairments referred for pre-driving assessment are neuromedical condition such as stroke; musculoskeletal condition such as congenital or acquired limb defects, orthopaedic deformities; neurological condition such as foot drop, spinal cord injury; and neurosurgical cases such as acquired brain injury. In the presence of cognitive dysfunction which are often associated with acquired brain injury and stroke, patients are advised as incompatible with safe driving)

Compared to on-road testing, driving simulators were claimed to be safer, more easily controlled and standardised, and allow for reproducible and easy modifiable conditions and scenarios. The driving simulators also thought as to provide objective methods of capturing driver-response data, can be used among high-risk populations, introduce more challenging environmental conditions and create more demanding task-based conditions such as multi-tasking.[7]

This technology review was requested by an Occupational Therapist from Hospital Tengku Ampuan Afzan (HTAA), Ministry of Health Malaysia in order to expand its usage in Ministry of Health facilities.

2.0 OBJECTIVE / AIM

To assess the efficacy/effectiveness, safety and cost-effectiveness of driving simulator for vehicle driving among patients with/recover from various health conditions such as stroke patients, brain injuries and visual impairment.

3.0 TECHNICAL FEATURES

3.1 Driving Simulator

Driving motor vehicle is a complex task that requires cognitive functions for decision making and multi-level integration of sensory, motor and cortical functions. There are three levels of skill and control in driving; strategic (planning) or general route planning, tactical (manoeuvring) and operational (control) levels which involved individual responsiveness to driving circumstances with controlled or automatic action pattern respectively.[9]

Meanwhile, the driving simulator determines the driving abilities by providing driving stimuli and assessing driving responses in various challenging, but in a safe environment.[9] The key elements of the driving simulator included software system, visual system and motion system.[5] However, the testing protocols of the driving simulators have not been standardised and their validity against actual road driving has not been established.[9]

There are various types of driving simulator with different brand and specifications such as Ford-Fiesta vehicle 1.8 car with automatic transmission, and Faros F-230 PMR driving simulator.[10]

Figure 1: The examples of driving simulator machine

Hirsch P. and Bellavance F. in their review stated that the driving simulators allow learners to:[4]

- Practice any manoeuvre, even dangerous ones, in a realistic and safe environment;
- Practice manoeuvres in distant or difficult-to-access locations at any time, e.g. expressways for learners who live an hour away from one;
- Experience the virtual consequences of their driving behaviours under a variety of realistic conditions (i.e. any weather, road and traffic condition, alone or in combination);
- Learn faster due to lower stress, better feedback and less wasted time;
- Control their learning pace (e.g. pause for a break at any time, do extra practice drills for any skill);
- Develop appropriate levels of self-confidence as they progress from easy to difficult and from simple to complex skills;
- View instant replays of their performances including overhead views;
- Practice complex visual and psychomotor skills until they can be performed automatically, e.g. lane changes;
- Receive computer-enhanced performance challenges and real-time feedback
- Receive reliable, objective performance scores, and;
- Improve their hazard anticipation, perception and response skills.

Besides that, Classen S. and Brooks J. in their review suggested five consensus statements to support the use of driving simulation technology among occupational therapy practitioners. By using the driving simulator, the occupational therapy practitioners may detect underlying impairments in driving performance, identify driving errors in at-risk drivers, differentiate between driving performance on impaired and healthy controls groups, show driving errors with absolute and relative validity compared to on-road studies and mitigate the onset of simulator sickness.[8]

3.2 Other alternatives

Instead of driving simulator test, there are several types of tests conducted to assess the driving abilities of the patients. Those tests are:[9]

1. Questionnaire

   The questionnaires were developed to assist physicians in their evaluation. There were different types of questionnaires for the evaluation. However, there was poor correlation between patient questionnaires and disease severity scales to determine medical fitness to drive. The discrepancy necessitates physicians to consider additional tests to evaluate the driving-related skills and abilities, including vision, cognition, motor/somatosensory function and neuropsychological testing (the so-called 'off-road testing battery).[9]

2. Off-Road Tests

   Off-road test was cognitive test that developed to evaluate a driving fitness which comprised road sign recognition, Dot cancellation (time and score), and square matrices with the direction and compass test. However, due to a lack of standardized parameters and protocols for the different off-road testing methods, off-road tests alone were not reliable as it could not predict the actual driving performance.[9]

3. On-road test (gold standard)

   In an on-road test, patients drive on a real, predetermined road course for 45–60 minute. The Certified Driving Rehabilitation Specialist (CDRS), or advanced-specialized occupational therapist or driver rehabilitation specialist that will be at passenger seat to observe. The observer will be assessing the patient driving performance, maintaining vehicle safety, and rating driving outcomes in a Global Rating Score (GRS) and a Sum of Manoeuvre Score (SMS). The GRS has 4 outcome grades, including pass, pass with recommendations, fail with potential for remediation, and fail. Although on-road tests were considered as reference standard, there were certain drawbacks, including availability, an inadequate amount of safety assurance for at-risk patients, and potentially inadequate testing resources for patients that need to be re-tested and re-certified each year. The on-road test observer can provide both a comprehensive evaluation of driving skills and recommendations for car modifications or tools to keep someone driving safely for as long as possible.[9]

4. Naturalistic driving

   Also known as naturalistic observation, is a new method for evaluating driving skills and abilities. Naturalistic driving longitudinally monitors unsafe behaviours via instrumentation in naturalistic driving settings. Naturalistic observation typically involves the use of the patient's car, which is equipped with devices that continuously monitor various aspects of driving behaviour, including information about vehicle movement, the driver, and the natural driving environment. This assessment method makes it possible to observe and analyse the interrelationship between the driver, and the vehicle, road, and other traffic in normal situations, conflict situations, and actual collisions.[9]

3.3 Study Populations

Study populations in the included studies in this TR were varied. The populations involved different types of illnesses which required further driving assessment before getting permissions to drive. Those populations were among elderly, patients that survived acquired brain injury (ABI), stroke, motor impairment, neurodegenerative disorders and low visions.

3.4 Driving simulator in Ministry of Health, Malaysia

Occupational Health Unit under Disease Control Division, Ministry of Health, Malaysia has come out with guidelines of medical standards for driving license for people with disabilities in 2011; Pre-Driving Assessment for People with Disabilities.

Table 1 is a data provided by Occupational Therapist on pre-driving assessment and training either with driving simulator or without driving simulator under MOH facilities. The data showed that there was a demand on the assessment and training of driving among patients with various physical and mental condition. Based on the data, the driving simulator only available in three states where one of it was broken (in Sarawak).[11]

According to the available Occupational Therapist statistic, the most common medical conditions referred for pre-driving assessment from the various specialities disciplines within Ministry of Health were:[11]

- Stroke (the most common)
- Traumatic Brain Injury (TBI)
- Amputation
- Dyslexia
- Learning disability
- Orthopaedic Cases
- Congenital deformity (upper / lower limb)
- Foot drop
- Autism Spectrum Disorder (least common and will be very selective)
- Hearing impairment (uncommon)
- Parkinson (uncommon)
- Spinal Cord Injury (SCI)
- Visual impairment (secondary to other illness such as stroke or TBI)

Table 1: Patients Statistic on Pre-Driving Assessment & Training Occupational Therapy (*Pemulihan Carakerja*) in MOH Hospitals in 2019 to August 2021

State	Driving assessment/training WITH driving simulator (DS)			Total WITH DS	Driving assessment / training WITHOUT driving simulator			Total WITHOUT DS
	2019	2020	2021		2019	2020	2021 (up to August	
Melaka	0	0	0	**0**	59	46	48	**153**
Pahang	0	0	0	**0**	64	74	33	**171**
Selangor	0	0	0	**0**	649	324	114	**1,087**
*Perak	49	48	17	**114**	627	366	206	**1,199**
Negeri Sembilan	0	0	0	**0**	113	49	34	**196**
Johor	0	0	0	**0**	510	560	334	**1,404**
Pulau Pinang	0	0	0	**0**	204	192	107	**503**
Kedah	0	0	0	**0**	356	370	164	**890**
Kelantan	0	0	0	**0**	51	35	64	**150**
**Sarawak	61	0	0	**61**	46	145	117	**308**
Sabah	0	0	0	**0**	398	181	112	**691**
***Wilayah Persekutuan (Kuala Lumpur, Putrajaya & Labuan)	1,056	1,457	711	**3,224**	273	210	299	**782**
Overall Total				**3,399**	**Overall total**			**7,534**

* Only in Hospital Taiping

**Driving simulator in Sarawak not functioning well since October 2019

***Only in Hospital Rehabilitation Cheras

4.0 METHODS

4.1 SEARCHING

Systematic search was conducted by the author and an *Information Specialist* for articles pertaining to driving simulator in patient with various illnesses including brain injury, vision loss and stroke

The following electronic databases were searched through the Ovid interface:

- MEDLINE® In-Process and Other Non-Indexed Citations and Ovid MEDLINE® 1946 to 1 September 2021

Other databases:

- PubMed
- Other websites: US FDA, INAHTA, CADTH

General databases such as Google and Yahoo were used to search for additional web-based materials and information. Additional articles retrieved from reviewing the bibliographies of retrieved articles. The search was limited to articles on human. There was no language limitation in the search. **Appendix 1** showed the detailed search strategies. The last search was conducted on 23rd September 2021.

4.2 SELECTION

A reviewer screened the titles and abstracts against the inclusion and exclusion criteria. Relevant articles were then critically appraised using *Critical Appraisal Skills Programme (CASP) checklist* and graded according to *US/ Canadian Preventive Services Task Force* (**Appendix 2**). RoB 2 is applied for RCTs. Data were extracted and summarised in evidence table as in **Appendix 3**.

The inclusion and exclusion criteria were:

Inclusion criteria:

a.	**Population**	Physical impairment patient, rehabilitation patient, hospital rehabilitation, neurological rehabilitation, rehabilitation, rehabilitation nursing, rehabilitation centres, stroke rehabilitation, physical disability
b.	**Intervention**	driving simulator, automobile driving, computer simulation, psychomotor performance
c.	**Comparator**	i. (Other assessment – refer under technical features)
d.	**Outcomes**	i. Safety ii. Efficacy and effectiveness
e.	**Study design**	Systematic review, cross-sectional, case-control, cohort
f.	Full text articles published in English	

Exclusion criteria:

a.	**Study design**	animal study
b.	Non-English full text articles	

5.0 RESULTS

Search results

An overview of the search is illustrated in **Figure 2**. A total of **79** records were identified through the Ovid interface and PubMed while **none** were identified from references of retrieved articles. After removal of duplicates and irrelevant titles, **66** titles were found to be potentially relevant and were screened using the inclusion and exclusion criteria. Of these, **58** relevant abstracts were retrieved in full text. After reading, appraising and applying the inclusion and exclusion criteria, **12** studies were included while **46** studies were excluded since the studies were already included in the systematic review and meta-analysis (n=6), narrative review (n=8) and studies driving simulator was not the main intervention (n=32). **Twelve** full text articles finally selected for this review comprised of five systematic review, two RCTs, three non-RCTs and two cross-sectional studies. The studies were conducted mainly in United States, Canada, United Kingdom, and Germany.

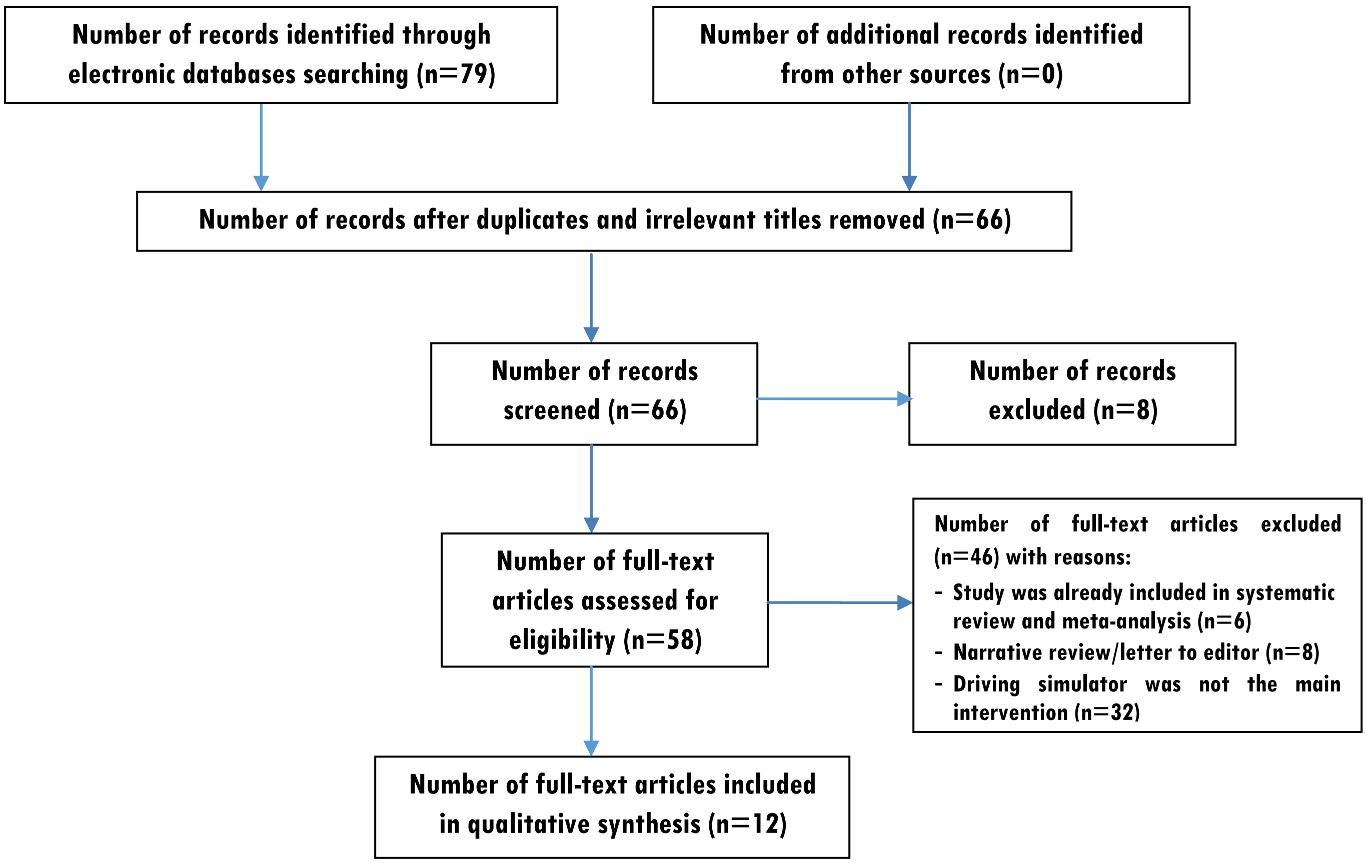

Figure 2: Flow chart of retrieval of articles used in the results

Quality assessment of the studies

The risk of bias in the included studies were assessed using domain-based evaluation adapted from the CASP checklist. This is achieved by answering a pre-specified question of those criteria assessed and assigning a judgement relating to the risk of bias as either:

Overall, the risk of bias was low for systematic review. However, the SRs included various types of studies included RCT, cross-sectional studies, case-control and other observational study. No meta-analyses conducted. Most of the included studies in this TR had small sample size which might not reflect the whole population of interest. The results of risk of bias of included studies are summarised in **Figure 3.1 and 3.4**

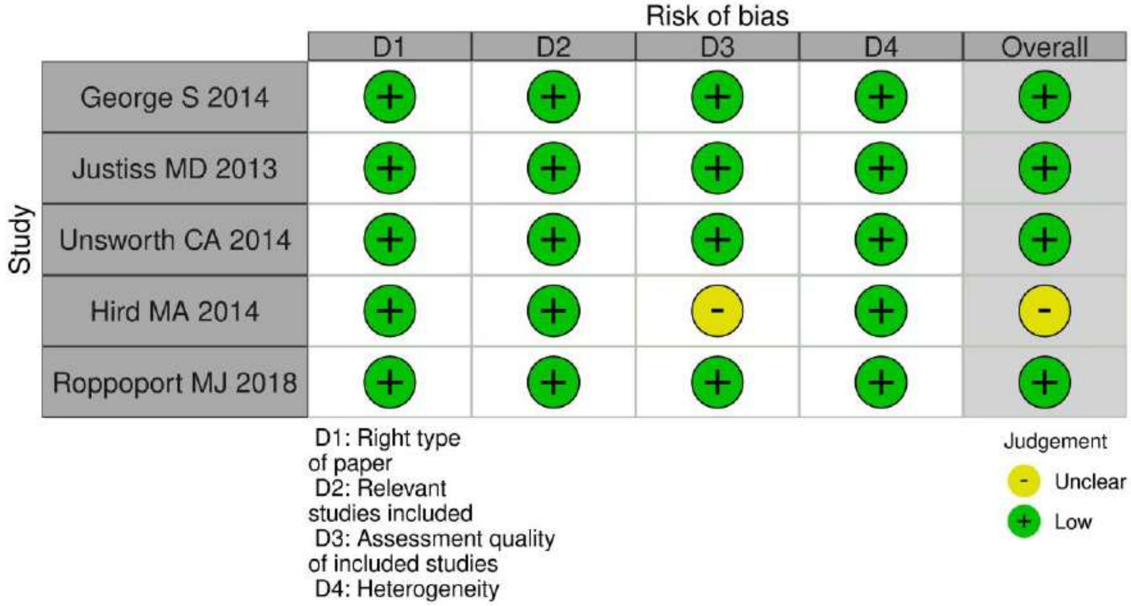

Figure 3.1: Risk of Bias of Systematic Reviews

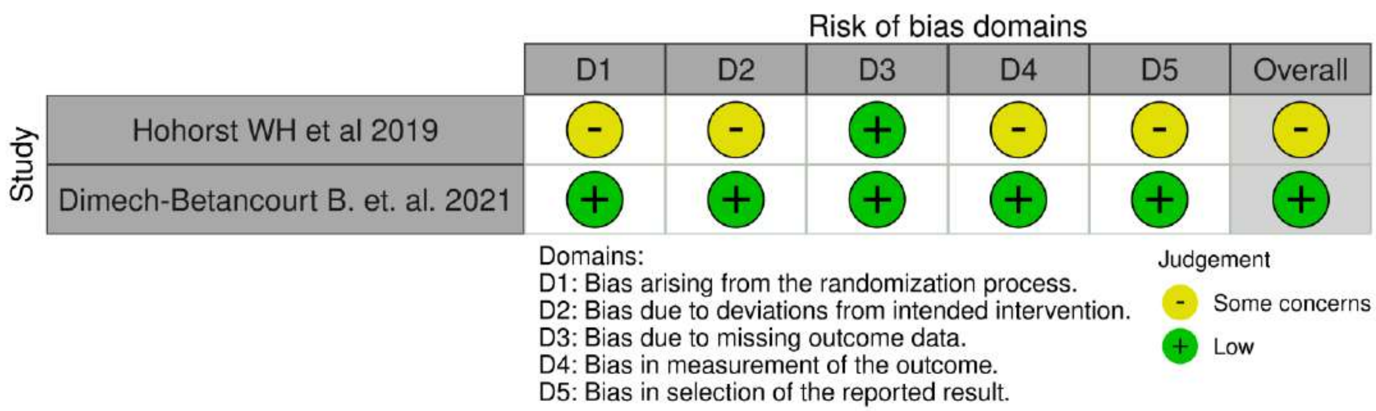

Figure 3.2: Risk of Bias of Randomised Control Trial

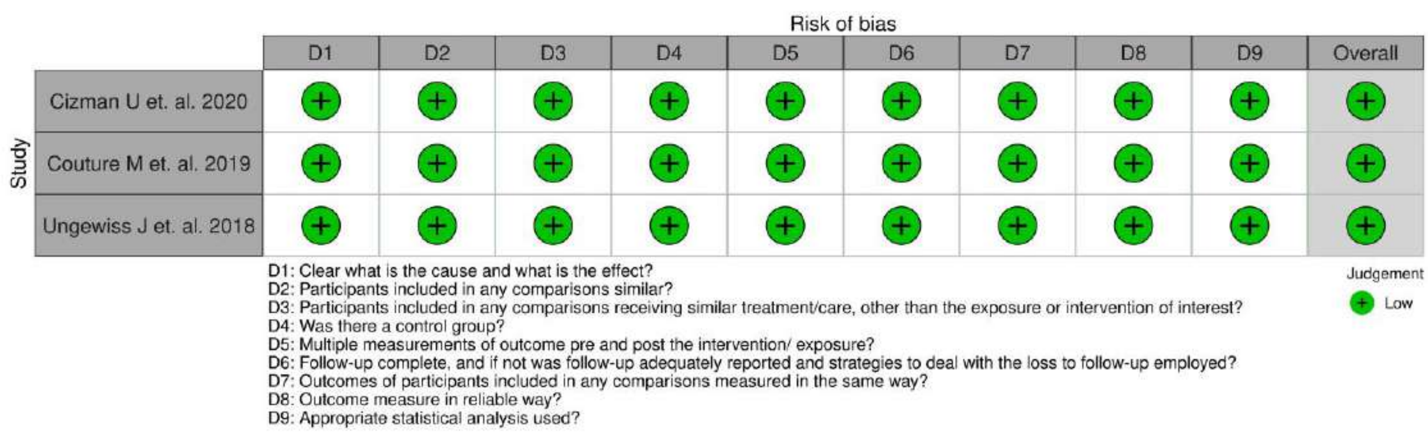

Figure 3.3: Risk of Bias of Non-Randomised Control Trial

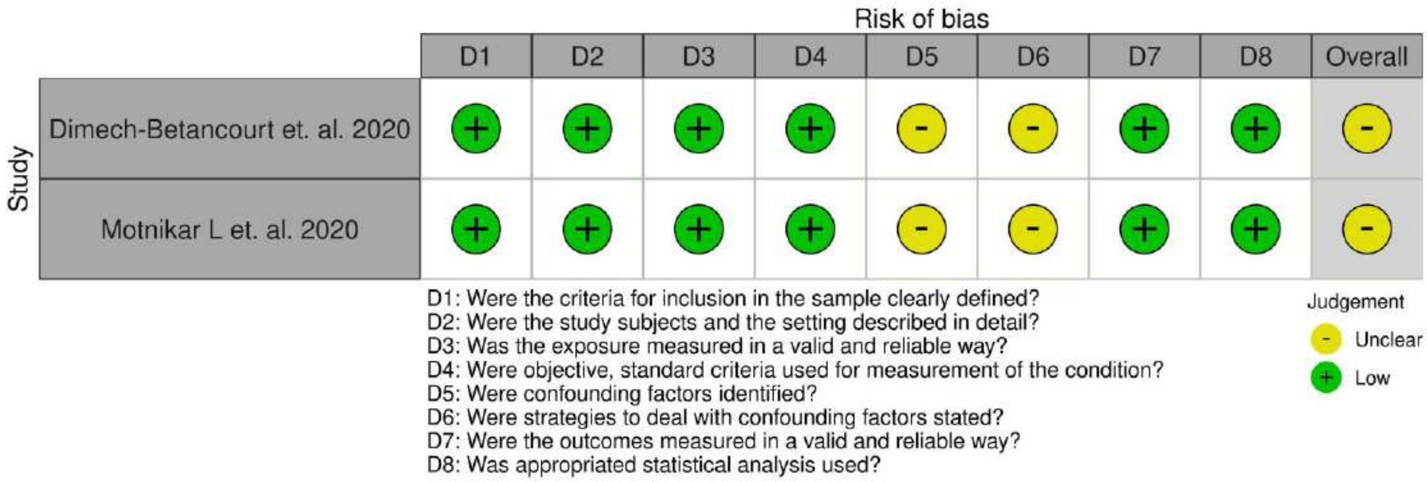

Figure 3.4: Risk of Bias of Cross-sectional Study

5.1 EFFICACY / EFFECTIVENESS

5.1.1 Driving Simulator as Driving Assessment Tool

An SR (Cochrane) by George S. which was published in 2014 to determine whether any intervention, with specific aim of maximising driving skills, improved the driving performance of people after stroke. The authors considered all rehabilitations interventions that aimed to improve driving skills included driving simulators that aimed at improving skills related to driving; physical interventions to improve mobility, strength and co-ordination; class training to improve driving knowledge and driving-related cognitive tasks. The primary outcome measurement was performance in an on-road assessment that was rated as dichotomous categorical outcomes (pass or fail) and the secondary outcomes were assessments of visual attention, reaction, visual scanning, self-efficacy, executive reasoning ability and test of visual perception, functional measures, physical measures of mobility, strength and co-ordination, and death. Four trials with 245 post-stroke participants with various levels of severity and stages were included in the SR. There were two approaches for driving rehabilitation after stroke were used; first was retraining the underlying skill deficits through training of perceptual, cognitive, physical or visual skills and second a contextual approach using driving simulators, on-road driving in the form of lessons and cognitive tasks with a context-specific focus. Two of the included studies compared the driving intervention with no intervention and another two trials compared commercially available software programs to train perceptual and cognitive skills with driving-related cognitive skills and driving-related cognitive tasks with off-the-shelf paper and pencil or puzzle tasks. The primary outcome showed that there was no clear evidence of improved on-road scores immediately after training with driving simulator in any of the four included studies at six months (mean difference 15 points on the Test Ride for Investigating Practical Fitness to Drive – Belgian version, 95% confidence interval (CI) 4.56 to 34.56, P-value = 0.15, one study with 83 participants). The secondary outcomes showed that road sign recognition was better in people who underwent training with driving simulator compared with control (mean difference 1.69 points on the Road Sign Recognition

Task of the Stroke Driver Screening Assessment, 95% CI 0.61 to 2.87, P-value = 0.007, one study with 73 participants). Although, significant findings were in favour of simulator-based driving rehabilitation programmes (based on one study with 73 participants) but the results should be interpreted with caution as they were based on a single study. Besides, there was insufficient evidence to draw conclusion on the effects of vision, other measures of cognition, motor and functional activities and driving behaviour with the intervention.[10, level 1]

One SR by Justiss MD in 2013 evaluated the effectiveness of interventions within the scope of occupational therapy practice to improve or maintain the driving performance and community mobility of ≥65-year-old subjects with low vision. Low vision was defined as a degree of visual impairment that cannot be corrected by eyeglasses or surgery and that interferes with daily functioning. Eight studies were included in the SR which identified the following driving and community mobility outcomes; crash risk, driving performance or behaviour either on–road or simulator, and out-of-home mobility. The four interventions themes identified in the included studies were driver simulator training, low vision rehabilitation for community mobility, driver education programs and low vision devices. As the concern of this TR was on driving simulator, the findings will highlight on driving simulator training. One of the included studies compared the 15-hours of training on driving stimulator training over the course of five-weeks with control group who received usual care. At followed-up assessments, 73% of the experimental group passed and could legally resume driving, whereas only 42% of control participants passed. The simulator-based performance outcomes showed significant reduction in collisions, pedestrian hits and total faults. However, the mixed age of participants and small number with vision impairments (<25%) limits its generalizability.[12, level 1]

Unsworth CA. et. al. also conducted an SR to identify which types of intervention approaches used by occupational therapists as part of driver rehabilitation programmes and to determine the effectiveness of those interventions. Sixteen studies which were published between 1969 and 2012 were included. The most common intervention approach used was computer-based driving simulator training (n = 8) and other interventions were off-road skill-specific training (n = 4) and off-road education programmes (n = 3). The participants involved was among patients with brain injury, physical and intellectual disability, stroke, patient with spinal injury and among elderly who hold a full driver's license for private standards car and those who aimed for obtaining a full driver's license for private standards car. Meanwhile, the interventions used aimed for driver rehabilitation and administered by an occupational therapy driver assessor (OTDA) in clinical practice. The on-road test was considered as gold-standard, thus, at least one outcomes measure for off-road test and computer-based driving simulator had to be related to on-road fitness-to-drive. All of eight computer-based driving simulator training studies included in the review used different types of software programme. There was also inconsistency with respect to the frequency, duration or total number of intervention sessions with the driving simulator; one study reported 25 sessions were completed by one client over a four-month period meanwhile other study had only one session. Similar variations also observed within the off-road skill-specific training and off-road educations programmes. For off-road training, the effectiveness of the training was supported by three studies and one of them was an RCT with 70 participants. Meanwhile for the effectiveness of computer-based driving simulator training, there were two RCTs with total number of 32 patients. However, for off-road education program, one study showed that off-road education program not effective as the authors observed that the results were influenced by many factors such as co-morbidities, age and driver experience. Most of the included studies were focused on a single diagnostic group and single intervention type, thus make it difficult to separate the effect of the diagnosis and severity impairments, from the effectiveness of the training, on the outcome of pass/fail on the on-road test. Inconsistent findings were observed for off-road skill-specific training either for older patients or stroke patient. On the other hand, the computer-based simulator training showed effectiveness in both older and acquired brain injury.[13, level 1]

Dimech-Betancourt B. et. al. conducted a recent RCT (pilot study) to investigate the feasibility and efficacy of a driving simulator intervention on driving outcomes following acquired brain injury. The study was a single-centre with two-arm parallel groups with blinded assessors within a clinical setting and was conducted from December 2016 to March 2019. The study involved 22 participants with acquired brain injury who were planning to return to driving post-injury. In an attempt to standardise severity across brain injury types, individuals were categorised into mild, moderate or severe based on clinical indicators. They were randomly assigned to either the experimental intervention (Simulator group, n = 13) or control group (Usual Care group, n = 9). The Usual Care group received general education about the impact of brain injury on driving and the evaluation process at the hospital. The simulator group received simulator training over eight sessions, two days per week, over four weeks in the month prior to completing on-road licensing assessment. The study was supervised by occupational therapists who were delivering the programme and documented any observations during the study sessions. The clinical outcomes and other observations during driving sessions will be documented and recorded based on certain scale and questionnaire such as Simulator Sickness Questionnaire to measure and document the incidence of simulator sickness, daytime Driving Comfort Scale to measure driver confidence, and 28-item Brain Injuring Driving Self-Awareness Measure to assess driver self-awareness. The participants also underwent an on-road driving assessment for licensing on public roads around the hospital. The on-road driving performance was measured using a modified version of the Driver Observation Schedule by an occupational therapy driver assessor, blinded to treatment allocation, using a standardised route. Towards the end of the study, 20 participants were followed up to their on-road assessment meanwhile the other two were withdrew (one in Simulator group and the other from Usual Care group). Twelve participants in Simulator group completed the intervention with 100% of intended treatment visits completed. Across the eight sessions, participants averaged 23.61 minutes (standard deviations; SD = 4.33) driving in country environments, 15.20 minutes (SD = 9.28) in city environments and 6.52 minutes (SD = 1.98) on the freeway/motorway. Types of goals discussed included improving reaction times, lane maintenance and confidence; however, most of the time participants found it challenging to articulate specific behavioural goals. The information was extracted from session records to generate a score for proportion of session completed. These categorised participants into low (<50%), medium (50% - 75%) and high >75%) completion categories. On average, there was high completion of programmes delivery with one participant session scoring in the medium range, and the other 11 scoring high completion (median; M = 86.16%, SD = 7.45, range = 67.64 – 100). Of the 12 individuals who completed in the Simulator group, six (50%) passed the on-road assessment while another six (50%) failed. One participant in the Simulator group passed with a license restriction specifying a 10km (from home) driving radius. Of those who failed on road assessment, five went on to complete on road driving lessons (M = 6.00 lessons, SD = 5.24), were re-assessed and passed. In the Usual Care group, six (75%) passed the on-road assessment while two failed (25%). Both completed on road lessons (M = 8.00 lessons, SD = 2.83), were re-assessed and passed, with one restricted to a 10km (from home) driving radius. Fisher's exact test revealed a small to medium effect size for pass/fail rate between groups (P = 0.373, ϕ=0.25). No participants were involved in a crash during the on-road assessment. Only one control participant required the use of an assistive aid (spinner knob) during the on-road assessment. Mann-Whitney U analyses revealed that medium to large effect size for critical error, lane errors and merging errors on road assessment and according to the Driver Observation Schedule scoring protocol, Usual Care group produced less errors than the Simulator group. Critical errors were attributed to poor speed regulation or failure to observe. For confidence, those in Usual Care group had a 9.73% reduction in confidence from baseline to end of the intervention. Those in Simulator group on the other hand, experienced 9.42% improvement in confidence. Furthermore, a medium effect size was found for anticipatory self-awareness discrepancy change scores between Usual Care and Simulator groups from baseline to post-intervention. However, analyses indicated that, on average, discrepancy reduced for the Usual Care group and increased with the Simulator group.[14, level II-1]

Hohorst WH et. al. conducted RCT to quantify the benefits of two degree of freedom motion feedback (2DoF) during simulated driving. This study investigated the performance, tolerance and perception of simulated driving, both with and without motion feedback, in healthy adult drivers. The simulated driving included 10 laps in racetrack environment and a 15-mile stretch of coastal highway driving. This kind of environment was purposely to investigate the impact of motion feedback on non-impaired drivers in challenging driving task. This study involved only six volunteers of non-impaired licensed driver at age of 18 to 22 years-old with at least two years of driving experience. The participants were randomly assigned to With Motion (n = 3; 2 males, 1 female) or Without Motion (n = 3 male) group. All participants completed their tasks accordingly. During Motion condition, two linear actuators provided the motion feedback in the form of pitch and roll rotation. The correlation between simulated vehicle dynamics and seat motion was managed with software and the correlation was tuned separately for each experimental task. For Without motion condition, the linear actuators were disabled. During the first experimental task, simulated Racetrack driving, the participants completed 10 laps without other vehicles on the track. Then during driving session, individual lap times were recorded and the authors recorded the observations of various infarctions included track violation, traction loss, and major incidence. The second experimental task simulated Highway driving, where the participants completed a 15-mile stretch of a dramatized portion of California Highway One. This course featured frequent elevation change and sharp turns which required regular acceleration, and deceleration to navigate successfully. After completing the tasks, the participants completed two surveys; Sickness Survey Questionnaire and 22 questions from the Intrinsic Motivation Inventory. During the Racetrack task, all participants drove at high speeds and consistently at or slightly above the posted speed limit during the Highway task. This situation showed that the participants interpreted the task correctly. First findings, with motion group showed shorter lap times than Without Motion group which suggested that motion feedback provided useful information for navigating the turns which might be difficult to judge without motion feedback. The feedback were the participants in With Motion group able to inform the sense of speed going into turns and the extent of braking executed before them. Second, both groups committed track violations and lost traction regularly. However, major accidents rarely happened in both groups. Third finding was regarding infraction where most of infractions during Highway task were lane violations which were lower in With Motion group. This observation actually showed that motion feedback provided useful information to help participants judge their speed as they slowed for corners in order to maintain the vehicle within the driving lane. Fourth findings were on simulator sickness. Surprisingly participants in the With Motion group reported lesser simulator sickness incidence than the participants in Without Motion group. The participants Without Motion group reported that they experienced considerable simulator sickness even two of them experienced symptom intensity in the 80-98 percentile of symptoms reported by pilots during simulated flight training. Fifth, the intrinsic motivation results reported that participants in With Motion group experienced greater enjoyment and perceived competence than those in without Motion group. However, one participant in With Motion group reported an elevated level of pressure and tension relative to the consistent level reported by Without Motion group. Lastly, perceived choice was marginally higher in With Motion group but this outcome measure require further assessment.[15, level II-1]

Cizmann U. et. al. conducted non-randomised control trial (non-RCT) study to test if neuropsychological assessment (NS) of attention and executive functions, driving simulator (DS) assessment was consistent; moderate to high correlations between variables. There were 99 participants (72 males, 27 females), aged from 20 to 59 years of age (mean = 48.98; standard deviation [SD] = 17.27) involved. On average, all participants had 12.10 years of education (SD = 2.54). Most of participants in the sample were survivors of traumatic brain injuries (38.4%). Others were ischaemic stroke (15.2%), multiple sclerosis (14.15) and brain tumour (11.1%). The included data was gathered at the Drivers medical unit at the University Rehabilitation Institute Soca in Slovenia according to the protocol of medical documentation and demographic data collection, neuropsychological assessment and driving simulator assessment. The authors reported that a simulator-based assessment provided ecologically valid measures that in some cases, may be more sensitive than traditional road test as predictors of long-term driving performance in the community. For this study, NERVTECH^{TM} DS was used and patients were asked to drive for 30 minutes in three different settings; a non-residential rural area, a four-lane and a high-traffic urban area. Each area has specific scenario which were generated to test the participant's responses and actions. The similar patients later on underwent NS test, for assessment of cognitive impairments and measured cognitive functioning in various domains of higher mental cognition. Different modules and tests were used to assess the attention skills, the speed of processing of any spontaneous act, the ability to maintain a central attentional focus, the inhibition of inappropriate behavioural responses, and to assess the ability to process two tasks in parallel. In order to reduce number of variables in the correlation analysis, the authors created compound scores of Attention components and the average number of errors and omissions (t-score) was calculated. For each scenario, the Pearson correlations coefficients between NS and DS were calculated; significant correlation of an NS-DS pair was above 0.25 per scenario. In rural driving scenario, the average reaction time in DS was weak, but significantly correlated with all NS except Tower of London Test (TOL) Total Correct Score. Participants with shorter reaction times in the DS had higher attention and executive function scores in NS. Those with a shorter Total Driving Time in DS managed to solve a practical problem in shorter period of time (TOL Total Executive time, r = -0.284). Although weak, the correlation for both techniques in rural scenario was significant for Selective Attention score and Stop Sign Violation Variable (r = -0.251). Another significant correlation was between distractibility and Off-Road Driving scores [%] (r = -0.256) indicated that there was a weak connection between the percentage of time the drive did not regularly check the rear-view mirror and being more distracted on the NS task. As for highway driving scenario, the authors also observed weak to moderate correlations between Average Reaction Time in DS with most NS variables except TOL Total Correct Score and Selective Attention. Better impulse control (Selective Attention) was associated with less time driving off-road (r = -0.352). On the other hand, participants who were better at maintaining attention, ignoring irrelevant information and suppressing inappropriate responses (Distractibility) were less likely to produce a jerky rise (r = -0.255), to irregularly use the rear-view mirror (r = -0.296) and to drive above the speed limit (r = -0.271). Meanwhile, participants with better executive planning skills (TOL Total Correct Score), produced a less jerky ride through-out the highway scenario. A Faster mental processing speed (TOL Total Executive Time) has associated with less time between checks of the rear-view mirror (r = -0.317). Lastly on urban driving scenario, those who were faster at completing the urban scenario Total Driving Time), had better psychomotor reaction speeds on the Alertness Task 9r = -0.300), better divided attention (r = -0.259), less distracted (r = -0.282) and spent less time solving a practical problem (TOL Total Executive Time) (r = -0.322). Besides that, faster mental planning and processing speed (TOL Total Executive Time, r = -0.272) was associated with less off-road driving (r = -0.272). Then, less distracted participants were less likely to drive above the speed limit (r = -0.293).[16, level II-1]

Another recent cross-sectional study by Motnikar L. et. al. was to identify driving characteristics of fit-, unfit- and conditionally fit-to-drive neurological patient population using a driving simulator with three high-risk scenarios; rural, highway and urban environments. The study included 91 neurological patients (31 subjects were deemed fit to drive, 32 unfit, and 28 under certain conditions) undergoing a multidisciplinary assessment for driver's license revalidation, consisted of a clinical, neuropsychological, functional, and on-road evaluation. The groups drove through three independent driving scenarios, during which a variety of measures describing reaction time, vehicular control, and traffic rules compliance were performed. The experiment lasted ~30 minutes. At the end of the assessment the researchers were able to differentiate the ability of the three groups. The fit- and unfit-to-drive population significantly differed ($p<0.05$) in reaction times, regardless of the scenario. No significant differences in traffic rule compliance or vehicular control parameters were observed in the rural environment ($p>0.05$). Based on post-hoc analysis, Bonferroni corrections was applied, the results showed that on the highway scenario, the unfit group exhibited greater variability of steering wheel angle ($p = 0.023$), higher steering reversal rate ($p = 0.020$), and a higher rate of turn signal errors ($p = 0.027$). In the urban environment, the unfit group had higher speeding rate ($p=0.013$) and greater number of accidents ($p = 0.016$). The unfit group had significantly higher lane position variability in the urban scenario compared to both fit ($p = 0.001$) and the conditional ($p = 0.018$) group. As for reaction times, the unfit group reacted significantly slower than both the fit and the conditional group in the rural scenario ($p = 0.018$ and $p = 0.18$, respectively) and highway scenario ($p = 0.000$ and $p = 0.000$, respectively). No significant differences were observed between the fit and the conditional group in any variable across the three groups. There also no correlation (range: -0.5 to 0.29) between neuropsychological tests and various simulator variables were also observed. This study showed that the driving simulators were able to capture differences between (fit and unfit-to-drive) neurological patient populations and therefore may have potential as a deficit-independent screening, assessment, or rehabilitation tool.[17, level II-2]

Ungewiss J. et al. conducted a non-RCT study to assess the agreement of the pass/fail rates between on-road and driving simulator conditions. The study involved 31 patients who were having glaucoma (10 patients), homonymous hemianopia (10 patients) and 20 patients with normal-sighted group age-matched as a control. All the patients were recruited by the Neuro-Ophthalmology service of the University of Tubingen, Germany. The driving simulator test was performed in the moving-base driving simulator at the Mercedes-Benz Technology Center and included nine hazardous situations that occurred at predefined positions during a route of 37.5km length. The average driving time for the entire course was approximately 40 minutes. The driving tasks consisted of two parts; first part was realistic scenario of 30.7km included four hazardous situations and second part of 6.8km which involved five hazardous situations. The masked driving evaluator will also score the simulator video recordings and determined if participants passed the simulator test. If the subjects failed one hazardous situation, the whole driving test was considered as failed. Meanwhile, the on-road driving test was performed in Tubingen area in collaboration with a driving school using a dual-brake vehicle of Audi Q5 type provided by the Research Centre for Computer Science. The route length for on-road driving test was 20.0km including various scenario. Depending on the daytime and the traffic volume, each drive lasted between 30 and 40 minutes. For this test, the driving instructor sat in the front passenger's seat and was responsible for the driving safety and the driving evaluator will sit at backseat and masked to the participant's 'virtual status' including driving skills. The practical driving test was considered failed if the candidate commits serious error which caused harmful act to the other road users, gross disregard of the rules and other errors. Due to simulator unavailability and technical problems, only 31 participants participated in driving simulator and on-road group; eight patients with HVFDs, seven normal controls (age-matched to the HVFD group), eight patients with binocular glaucomatous visual field defects and eight normal controls (age-matched to the glaucoma group). Based on the observation and analysis, the authors reported that the majority of failures occurred at initial phase of each sub-session especially at location with a pedestrian crossing from the left. Table 2 showed the number of participants passed the driving test. With regard to the agreement between on-road and driving simulator test, three out of eight HVFDs patients, four out of eight glaucoma patients and 11 out of 15 normal controls passed both tests. On the other hand, three out of eight HVFDs patients, two out of eight glaucoma patients and one out of 15 normal controls failed both tests. Thus, 24 out of 31 participants showed concordant results with regard to the on-road driving test and the driving simulator test whereas the remaining seven subjects showed discordant outcomes (only one test passed). The authors did a modified McNemar test and they found that there was a good agreement between the results of on-road and simulator driving. The sensitivity of the on-road and simulator driving test to identify subjects with visual field defects via driving failures was low; 7/15 for both tests. The specificity was comparatively high with 12/15 for on-road testing and 13/15 for the simulator, however, it did not withstand the requirement given for regular 'screening' methods.[18, level II-1]

Table 2: Number of participants passed the driving test

Test / Participants	HVFDs group (N=8)	Binocular glaucomatous Visual loss group (N=8)	Control group (N=15)
Driving simulator	8	5	13
On-road driving test	4	5	12

5.2 Patient Satisfaction towards driving simulator

Couture M. et. al. conducted a non-RCT trial with a static group comparison study to compare the advantages of DS versus on-road driving. For experimental (EXP) group, 16 participants (13 men and three women) from Driving Training and Assessment Programme (DTAP) were invited to receive simulator-based training with assistive technologies for driving. Four of the participants have paraplegia-tetraplegia, seven with orthopaedic condition or amputation and five with neurologic disease. Meanwhile for static comparison (CMP) group, the samples were from data-base of clinical file from the last 10-years (2008 – 2018) of DTAP participants who received training on the road with similar inclusion and exclusion criteria as experimented group. The occupational therapist-principal investigator (MC) conducted the driving-simulator training in the presence of driving-instructor. The MC will ensure the training goals were achieved and also responsible to compile the number of training sessions and the presence of physical discomfort using a participant questionnaire at the end of each session. After the simulator training, the participants were directed back to the occupational therapist who performed the initial on-road assessment as part of the comprehensive driving assessment for an on-road test. This occupational therapist was blinded to the simulator training. The participants in the experimented group completed simulator-based training with one or more assistive technologies. During simulator-based driving, the driving instructor will choose driving scenarios based on the gradation identified by the occupational therapist. The scenario began with straight lines driving without the presence of another vehicle. The crossing intersections, lane changes and turns were gradually introduced as well as the level of traffic. If the participant achieved the intended objective, showed no progression after three consecutive session or completed seven sessions, the occupational therapist will end the training on DS and referred the participant for the on-road test. Meanwhile for CMP group, the participants underwent training on the use of adapted driving devices on the road. The outcome measures for experimented group was collected using sociodemographic questionnaire for demographic data, simulator intervention follow-up chart for any achievement of the interventions, standard road test to evaluate for any different aspects of driving, observation based on Michon's model that was described based on three interdependent and hierarchical decision-making levels (strategic, tactical and operational), simulator satisfaction questionnaire, and French simulator sickness questionnaire. For the CMP group, the results of the road test, the reason for unsafe driving if applicable and number of sessions required for on-road training were collected from the database. The authors reported that for level of safety between groups, there was no statistical difference; $p = 0.126$, however, both groups experienced more tactical difficulties during road test. During simulator training, 15 out of 17 participants (88%) reported sickness at session one. The sickness was gradually decreased throughout the training session reaching 0% by session six. The intensity of all types of discomfort were reported as mild (27 cases), moderate (three cases) and severe (two cases). The most reported type of discomfort were dizziness and general discomfort. As for level of satisfaction upon completion of simulator training, the participants reported being satisfied/very satisfied with training on a simulator with driving assistive technologies 76% to 100% of the time. All participants also satisfied/very satisfied with completion of simulator session before starting to drive with new adaptive driving device. However, lower proportion of participants reported being satisfied/very satisfied with simplicity of use (42%), realism of the driving experience (6%) and well-being felt or experienced (59%). Based on the occupational therapist's clinical observations following the last simulator training session, the therapist expressed many advantages and some disadvantages regarding the use of driving simulator. First advantages, the driving simulator allowed the participants to begin to learn how to operate a vehicle with a new assistive technology in safe context by eliminating the traffic and starting with a straight route. Secondly, with DS, the driving tasks can be broken down into subtasks to reduce mental load when learning and to develop automatisms at any context such as use of secondary controls and level of traffic that being gradually introduced. Third was the difficulties observed in the DS helped in identifying problems that were then observed on the road. Fourth, the driving skills learned on a simulator can be transferred to on-road driving. Lastly, simulator training was available for free of charge compared to on-road training.[19, level II-1]

A recent cross-sectional study by Dimech–Betancourt B. et. al, published in 2020 examined the user experience of driving simulator intervention for acquired brain injury (ABI) survivors as well as to understand the benefits and limitations of the driving simulator training intervention and to identify facilitators and barriers to participation. Semi-structured interviews were conducted with 14 individuals (12 ABI survivors and 2 occupational therapist driver assessors who facilitated the intervention). The face-to-face interview scheduled comprised of several open-ended questions, developed by the researchers, regarding reasons for participant interest in the intervention, helpful and unhelpful scenarios, aspects of the programme that were easy or challenging, experience of simulator sickness and whether the programme would be recommended for other brain-injured patients. Participants were recruited from community-dwelling ABI survivors in a pilot RCT comparing a driving simulator intervention to standard care. The standard care involved generic education about return to driving after brain injury and waiting for medical clearance to resume driving or undertake occupational therapy driving assessment. Thematic analysis was adopted to analyse the interview data. The thematic analysis identified 6 themes related to experience and perceptions of the simulator training intervention: (1) Evolving driver self-concept; (2) Developing skills required for safe driving; (3) Individual differences at entry; (4) Interaction with simulator technology; (5) Perceived appropriateness of intervention content and delivery; and (6) Overall acceptability and experience of the simulator intervention. The findings suggested that individual differences (e.g., anxiety, previous experience) influenced participant response to the training. The driving simulator allowed participants to practise various driving skills, re-familiarize themselves with the task of driving, and prepare for return to on-road driving within a safe environment. The intervention also perceived to be useful for enhancing driver self-awareness, autonomy, confidence and patience. The participants also reported that the simulator was relevant to practise various operational and tactical behaviours including lane changing, signalling, steering and making turns, braking and reaction time, lane positioning and following distance. However, the participants commonly reported that speed regulation was too difficult to train. Overall, the simulator intervention was reported to be a positive experience for the participants.[2, level II-2]

5.3 Accident risk assessment

Hird MA. et al. in another SR provide a literature on cognitive, on-road performance, simulator-based assessment, or a combination of three and to address the existing limitations and inconsistencies in stroke and driving research. Twenty-two studies published within January 1998 to July 2013 were included. The studies involved 16 cognitive assessments, 17 on-road assessment and three simulator assessments. High degree of heterogeneity between studies and among participants were reported. Based on the included studies on driving simulators, one studies that compared the simulated driving performance of middle cerebral artery (MCA) stroke patients (n = 24), vertebrobasilar stroke patients (n = 8) and healthy controls (n = 12) showed that there was no significant difference in accident rates between stroke patients as a whole and controls. However, after removing TIA patients (n = 10) from the analysis, results suggested that patients with complete strokes had significantly more accidents than control participants ($P < 0.05$). Patients with MCA strokes had significantly higher accident rate compared to controls (2.88 ± 3.6 versus 1.25 ± 1.36; $P < 0.05$) and showed an increased rate in accidents and concentration faults compared with vertebrobasilar stroke patients ($P < 0.05$). Another included study reported that the stroke patients (n = 30) performed significantly worse on a simulator evaluation ($P < 0.001$) compared with healthy controls (n = 30). However, one study found no significant difference between patients and controls across several driving simulator variables including time to collision, distance to collision, and complex reaction time. The simulator performance also not associated with on-road performance.[1, level 1]

Ropoport MJ et al. conducted an SR to determine whether the presence of stroke and/or transient ischaemic attack (TIA) was associated with an increase of motor vehicle collision (MVC). The included studies involved participants with ischaemic or haemorrhagic stroke or TIA of any severity. The primary outcome measures of the SR were related to the road MVs (self- or informant-reported data, state/government accident registries) and MVCs recorder on a computerised driving simulator. The SR included twelve studies consisted of three case-controls, five cohort studies, and four cross-sectional studies using simulators. The three case-control studies were conducted in United States (US) that consisted of participants at aged of 55-years old and above with history of stroke. The ascertained MVCs used either collision or health databases and the history of stroke was ascertained using subjective report including medical records. One of the case-control studies showed an increased risk of stroke in those with at-fault MVCs (7.8%) compared with those without MVCs (4.1%, OR 1.9, 95% CI 1.0 – 3.9). The other two case-control studies did not show between-group differences. Three out of five cohort studies, were conducted in US, and the other two were from Sweden and Norway. The MVC records were from state records and self-report, meanwhile stroke history was from hospital records and self-report. The time between stroke and MVC was a maximum of one year, and nine years in three studies and undetermined in the other studies. Only one cohort study indicated an increased rate of MVC in those with stroke or TIA with rate of 9.8% compared with 4.0% in those with no medical diagnosis, RR 2.71 (95% CI 1.11 – 6.61, $p = 0.03$). One study reported greater rates of MVCs reported to insurance companies; three out of nine of patient with stroke history compared with one of 22 healthy controls. As for cross-sectional studies with computerized driving simulators, all four studies were conducted in Canada, Australia, United States and Germany with sample size ranged from six to 32. The timing of the simulated driving assessment varied, within a week of stroke to at least six months following stroke. In the cross-sectional studies, stroke was based on clinical diagnosis and one study involved stroke with TIA participants and one study involved hemianopsia due to stroke. The SR reported two of the cross-sectional studies showed significant findings on the rate of MVCs in the driving simulator. First, the MVCs rate was significantly more than double among those who had a remote stroke (average of 3.5 years earlier) relative to healthy controls and second, the risk of simulated MVCs within two weeks of the stroke was significantly more than doubled for those with a middle cerebral artery stroke but not for the group as a whole relative to healthy controls. One of the studies also reported that driving error occurred twice as often in those with stroke than controls, though there was no increase in MVCs.[20, level 1]

5.2 SAFETY

Dimech–Betancourt et al. reported that their cross-sectional study showed that the fidelity and simulator sickness were considered limitations of the simulator technology. Eight participants (66.74%) experienced some of simulator sickness including headaches, heaviness in the head, eye-strain, difficulty focusing and dizziness or vertigo. The patients also articulated the situations which appeared to predict the onset of symptoms including sharp movements of the screen, increases in environmental stimuli and going around corners.[6, level II-2]

Dimech-Betancourt et. al. in their RCT reported five minor adverse events in the Simulator group. Four were nausea and fatigue which were related to simulator sickness. Other event was related to upper limb soreness from prolonged use of the steering wheel. The minor events were resolved with rest. There was one serious adverse event reported due to repeat stroke in one of the Usual Care group participants. However, it was confirmed not related to the study. A completion rate of 67.7% was obtained for the Simulator Sickness Questionnaire across sessions. Individual symptom severity was on average rated in the slight range at early Sessions 1-2, mid Sessions 3-6 and late Sessions 7-8. No subscale scores fell in the moderate to severe ranges. During early sessions, 10.53% of participants reported slight oculomotor symptoms and 5.26% slight nausea and disorientation symptoms. The most commonly endorsed symptoms were difficulty focusing, general discomfort, fatigue, nausea and difficulty concentrating. Mid-intervention, 23.33% of participants reported slight oculomotor symptoms, 6.67% reported slight nausea symptoms and 13.33% reported slight disorientation symptoms. The most report symptoms reported were fatigue, eye strain and difficult to focus. Finally, during the late sessions, 35.71% of participants reported slight oculomotor symptoms, while other symptoms were in the negligible range. At this stage, the most common reported symptoms were fatigue, eye strain, fullness of head and dizziness with eyes open.[14, level II-1]

5.3 ORGANISATIONAL ISSUES

Couture M. et. al. reported the disadvantage of driving simulator due to technical problem of the device. The occupational therapist reported that some of the adapted devices were attached to the simulator but not functioning and required secondary controls. The simulator training also involved some delays (10 times of 70 practices sessions) due to malfunction of the simulator.[19, level II-1]

Another study by Ungewiss J. et. al. reported a few numbers of participants had to drop-out because of unavailability of the simulator as well as technical problems happened.[18, level II-2]

5.4 ECONOMIC IMPLICATION

There was no retrievable cost-effectiveness study related to driving simulator for driving assessment among patients. The market price of driving simulator varies depends on difference specifications[21], ranges from RM10,000 to RM600,000. In Malaysia, Ministry of Health National Rehabilitation Hospital in Cheras and Ministry of Education International Islamic University in Kuantan has been using driving simulator SIMULASIA-SA-3500-R (Figure 2). In 2021 this device is priced at RM358,000.

Figure 2: SIMULASIA-SA-3500-R

For Ministry of Health patients referred for driving stimulator in Ministry of Health facilities, the fee charges are as follows (Sources in 2021):

- Driving assessment and training: RM148.25
- Work assessment and hardening: RM100.70

- Consultation and examination room: RM10.00
- Registration (Initial): RM15
- Registration (Follow up): RM10

This shall incur a total first evaluation cost of RM273.32 per patient and RM20.00 for each follow up.

Based on the highest available referral data for pre-driving assessment from 2019 - 2021 that is within the Johor state, the calculated cost for 1,404 patients are RM386,741.28. With the projection of escalating referral trend, procurement of this device within more Ministry of Health facilities shall benefit more patients in the near future.

5.5 LIMITATIONS

We acknowledge some limitations in our review and these should be considered when interpreting the results. The selection of the studies and appraisal was done by one reviewer. Besides, only English full text articles were included. There is also related full text articles could not retrieve because of database limitation.

6.0 CONCLUSION

Based on the review, the outcomes of the driving simulator varied depending on types of illnesses, driving simulators specifications, and driving environments.

The retrievable evidence showed that, the driving simulator able to assess the capabilities of the patients in controlling their physical/sensory skills, and cognitive-perceptual while taking turn, break or handling any emergency reactions while driving. It enables the assessor to determine whether the patients can return to drive or not. The driving simulator allowed the patients to practise various driving skills, re-familiarize themselves with the task of driving and prepare for return to on-road driving within a safe environment.

In terms of safety, simulator sickness occurred such as headaches, heaviness in the head, eye-strain and difficulty focusing and dizziness/vertigo due to sharp movements of the screen, increases in environmental stimuli and going around corners. Others were fatigue, nausea, general discomfort and upper limbs soreness due to prolong used of the steering wheels.

There was no study on cost-effectiveness of driving simulator retrieved, however, the price for the driving simulator machine was varied depends on types, brands and specifications.

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8.0 APPENDIX

APPENDIX 1: LITERATURE SEARCH STRATEGY

13 August 2021

Database: Ovid MEDLINE(R) and In-Process, In-Data-Review & Other Non-Indexed Citations <1946 to August 12, 2021>

Search Strategy:

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1. Rehabilitation/ or Rehabilitation Nursing/ or Hospitals, Rehabilitation/ or Stroke Rehabilitation/ or Neurological Rehabilitation/ or Rehabilitation Centers/
2. (disability adj1 evaluat*).tw.
3. (hospital$ adj1 rehab*).tw.
4. (neurolog* adj1 rehab*).tw.
5. neurorehab*.tw.
6. rehab*.tw.
7. Disabled Persons/
8. (Disable* adj1 evaluat*).tw.
9. recover* of function*.tw.
10. (rehab* adj1 nurs*).tw.
11. (rehab* adj1 center$).tw.
12. (stroke adj1 rehab*).tw.
13. 1 or 2 or 3 or 4 or 5 or 6 or 7 or 8 or 9 or 10 or 11
14. (disable* adj2 (person$ or people$)).tw.
15. (disability adj2 (person$ or people$)).tw.
16. (physical* adj challeng*).tw.
17. (physical* adj disable*).tw.
18. (physical* adj disability).tw.
19. (physical* adj handicap*).tw.
20. handicap*.tw. (24005)
21. (automobile adj1 driv*).tw.
22. (computer* adj1 model$).tw.
23. in silico$.tw.
24. (computer* adj1 simulat*).tw.
25. (visual* motor* adj coordinat*).tw.
26. (motor* coordinat* adj visual*).tw.
27. (motor* perform* adj sensor*).tw.
28. (sensor* motor* adj perform*).tw.
29. (perceptual adj motor* perform*).tw.
30. (psychomotor adj perform*).tw.
31. Computer Simulation/
32. Computer Simulation/ or Automobile Driving/ or Psychomotor Performance/
33. (driv* adj simulat*).tw.

Other Databases

EBM Reviews - Health Technology Assessment
EBM Reviews - Cochrane database of systematic reviews
EBM Reviews - Cochrane Central Registered of Controlled Trials
EBM Reviews - Database of Abstracts of Review of Effects
EBM Reviews - NHS economic evaluation database

} Same MeSH, keywords, limits used as per MEDLINE search

PubMed
INAHTA
US FDA

} Same MeSH and keywords as per MEDLINE search

APPENDIX 2: HIERARCHY OF EVIDENCE FOR EFFECTIVENESS

DESIGNATION OF LEVELS OF EVIDENCE

I	Evidence obtained from at least one properly designed randomized controlled trial.
II-I	Evidence obtained from well-designed controlled trials without randomization.
II-2	Evidence obtained from well-designed cohort or case-control analytic studies, preferably from more than one centre or research group.
II-3	Evidence obtained from multiple time series with or without the intervention. Dramatic results in uncontrolled experiments (such as the results of the introduction of penicillin treatment in the 1940s) could also be regarded as this type of evidence.
III	Opinions or respected authorities, based on clinical experience; descriptive studies and case reports; or reports of expert committees.

SOURCE: US/CANADIAN PREVENTIVE SERVICES TASK FORCE (Harris 2001)

APPENDIX 3: EVIDENCE TABLE

(AVAILABLE UPON REQUEST)

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9 7 8 9 6 7 2 8 8 7 2 2 5