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Do mindfulness interventions improve road safety? A systematic review

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ABSTRACT

Mindfulness has been identified as a potentially effective intervention for reducing road trauma. In this paper, we report on the results of a systematic review which examined the evidence regarding the relationship between mindfulness and road safety. The review was conducted following PRISMA guidelines (PROSPERO 2017: CRD42017075704). The primary outcomes measured were crash or near-crash rates and the secondary outcomes were driving violations (including speeding and texting while driving) and driving performance (i.e., errors in driving simulator, etc.). This review was registered with PROSPERO 2017: CRD42017075704. A systematic search of databases from the disciplines of public health, psychology and transport safety (Ovid Cochrane Library, Ovid PsycINFO, Ovid EMBASE, CINAHL PLUS, Ovid TRANSPORT and TRID: TRIS and ITRD database) was conducted on February 7th 2018. Seventeen studies (12 cross-sectional and 5 case-control) published between 2011 and 2017 met the inclusion criteria. These all focused on the association between mindfulness or mind-wandering on road safety measures including driving performance (vehicle control, reaction time), compliance with speed zones and traffic signals, near-crash and crash rates, as well as propensity to engage in distracted driving behaviours. The results of the review suggest that mindfulness may be particularly useful for preventing distracted driving. However, a number of limitations in the existing research are noted. It is clear that more research is warranted to specifically investigate the effectiveness of mindfulness as an intervention for reducing road trauma.

1. Introduction

1.1. Rationale

Road trauma remains a significant issue in Australia. In 2017, more than 1200 road users were killed and approximately 36,000 sustained serious injuries in motor vehicle crashes occurring on Australian roads (Bureau of Infrastructure, Transport and Regional Economics, 2018). The estimated economic cost of road crashes to the Australian community is enormous – estimated at $AUD 27 billion per annum (Department of Infrastructure, Regional Development and Cities, 2018). The impact of road trauma includes private costs to individual road users and their families, as well as impacts to other road users, hospitals and the wider health system, workplaces, and governments (Bureau of Infrastructure, Transport and Regional Economics, 2018). These economic costs are accompanied by devastating social impacts for the families of those involved and for the broader community.

Recently *'mindfulness'* has been identified as a potentially effective intervention for reducing road trauma (Brown and Ryan, 2003). Several conceptualisations of mindfulness from clinical and socio-psychological research have been applied to study driving behaviour. For example, Kabat-Zinn (2005) defined mindfulness as the act of paying purposeful attention to the present moment, with openness and acceptance. Similarly, Baer et al., (2006) referred to mindfulness as the non-judgemental observation of ongoing internal and external stimuli. One of the most widely accepted conceptualisations of mindfulness in road safety research was proposed by Brown and Ryan (2003) who defined it as increased attention to and awareness of experiences in the present moment. This definition emphasises attention and awareness as key features of mindfulness (King et al., 2011); awareness refers to the monitoring of internal and external environments and the capacity to recognise and acknowledge internal and external events at any given

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moment while attention involves conscious examination of experiences in the current moment.

Another way of conceptualising mindfulness relates to the self-regulation of attention. Self-regulation of attention involves a deliberate, focused awareness of one's moment-to-moment internal and external experiences (Germer et al., 2017; Shapiro et al., 2006; Siegel et al., 2009) comprising the ability to: 1) anchor attention to objects for prolonged periods (i.e., sustained attention); 2) intentionally switch attention between objects or mental sets (i.e., switching) (Posner, 1980), and 3) suppress secondary elaborative processing of thoughts, feelings, and sensations (i.e. cognitive inhibition) (Heeren et al., 2009). All of the attributes of attention regulation are extremely relevant to driving where vigilance, rapid and frequent switching of attention, and avoiding distraction related to less relevant stimuli are important for driver safety and behaviour (Groeger, 2000).

Mindfulness has been applied across a range of lifestyle practices and therapeutic interventions, particularly for emotion and attention regulation disorders (Arch and Craske, 2010; Schmertz et al., 2009). The origins of mindfulness-based interventions (MBIs) or meditation practices stem from Kabat-Zinn (1982) mindfulness-based stress reduction programs which treated patients with chronic pain and stress related disorders. Several additional intervention approaches have been developed including Mindfulness-Based Cognitive Therapy (Segal et al., 2002) for relapse prevention for major depression, Dialectical Behaviour Therapy (Linehan, 1993) for chronic suicidal and self-injury behaviour for patients with borderline personality disorder, relapse prevention (Marlatt and Gordon, 1985) for providing coping strategies for substance abuse urges and Acceptance and Commitment Therapy (Hayes et al., 1999) for greater well-being by overcoming control or avoidance of negative thoughts and emotions.

When applied in the road safety context, mindfulness may play a significant role in improving driving behaviour, including preventing aberrant driving behaviours, driving aggression and distraction. Aberrant driving behaviours, such as violations and errors, represent a significant threat to road safety (Gras et al., 2006). These behaviours can be intentional with common examples including deliberate violations of traffic regulations, such as driving above the posted speed limit or aggressive violations used to express one's driving anger (Stephens and Fitzharris, 2016). Aberrant behaviours may also be unintentional and related to lapses or errors like braking too quickly on a slippery road. Given that mindful practices include the self-regulation of attention, higher levels of mindfulness are likely to be related to more attentive driving and a reduction in driving related errors or lapses (Koppel et al., 2018).

Another example of how increased mindfulness can improve driving safety is in relation to driving anger and aggression; which have been associated with increased driving violations and dangerous driving behaviours (Deffenbacher et al., 2016). Studies on driving anger have shown that individuals may hold pre-existing negative thoughts regarding other road users, which can exacerbate anger in response to driving circumstances (Stephens and Groeger, 2011, 2014). In addition, when drivers are angry, they are likely to make more superficial assessments of the driving situation, attributing blame on other drivers for situations that may be out of their control (Stephens and Groeger, 2014). Drivers who are prone to anger tend to express this anger through aggressive driving behaviours such as sounding the horn or chasing another driver in retaliation (Deffenbacher et al., 2002). Therefore, drivers who have more mindful driving styles, incorporating non-judgemental assessments of the current driving situation (and not relying on pre-existing negative schemas) would be less likely to react to situations with anger or aggression (Stephens et al., 2018). Indeed, mindfulness techniques have been considered an effective form of reducing rumination and increasing emotion-regulation, metacognitive awareness and acceptance, thereby facilitating drivers towards more adaptive rather than reactive thought processes (Fix and Fix, 2013).

Distracted driving poses an additional threat to the safety of drivers and other road users. Various sources of distraction, including conversations with passengers and interactions with on-board and portable technology, may place increased visual and cognitive demand on the driver and impair their driving performance (Hanowski et al., 2005; Heck and Carlos, 2008). In addition to secondary tasks, drivers may also be distracted by internal processes such as off-task thoughts, a phenomenon related to mind-wandering (Smallwood and Schooler, 2006). Mind-wandering is defined as task unrelated thought and occurs when individuals consciously focus on stimuli or events unrelated to task-related information received by the senses (Smallwood et al., 2003). Mindfulness has the potential to reduce distracted driving by promoting greater situation awareness of the driving environment, enhancing concentration and assisting drivers to maintain selective and sustained attention (Kass et al., 2011; Langer and Moldoveanu, 2000).

1.2. Objective

In the road safety context, few studies have applied mindfulness interventions as a preventative behavioural measure. The aim of this study was to conduct a systematic review to examine the evidence regarding the relationship between mindfulness and road safety, measured by primary outcomes (i.e., crash or near-crash rates), and secondary outcomes (i.e., aberrant driving behaviours, including speeding and texting while driving, or decrements in driving performance [i.e., such as errors] in a driving simulator, etc.).

2. Methods

2.1. Protocol and registration

The review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) (Liberati et al., 2009; Moher et al., 2009) (see Fig. 1) which provides a detailed guideline on the conduct and reporting style for systematic reviews and meta-analyses. The protocol for this review was registered with PROSPERO 2017 CRD42017075704.

2.2. Eligibility criteria

2.2.1. Inclusion criteria

Studies that met the following criteria were included in the review:

i full-text, original research in a peer reviewed journal;
ii published in English language and human studies;
iii included drivers aged 16 years and older;
iv used quantitative methods for data collection and analysis, supported by statistical analysis, and
v examined the relationship between mindfulness and road safety or related variables. Studies that reported one or more of the following outcomes were eligible for inclusion:

- primary outcomes: road safety, measured primarily by crash or near-crash rates, and
- secondary outcomes: aberrant driving behaviours, including speeding and texting while driving, or decrements in driving performance [i.e., such as errors] in a driving simulator, etc.

For the purposes of this review, the most relevant definition of mindfulness in the driving context, as determined by several studies (Abdul Hanan et al., 2010; Valero-Mora et al., 2015), was by Brown and Ryan (2003) who stated that it involved increased attention to, awareness and acceptance of current experience or present reality. Related definitions that described mindfulness as paying purposeful and non-judgemental attention to the present moment (Kabat-Zinn, 2003; Baer et al., 2003) were also included.

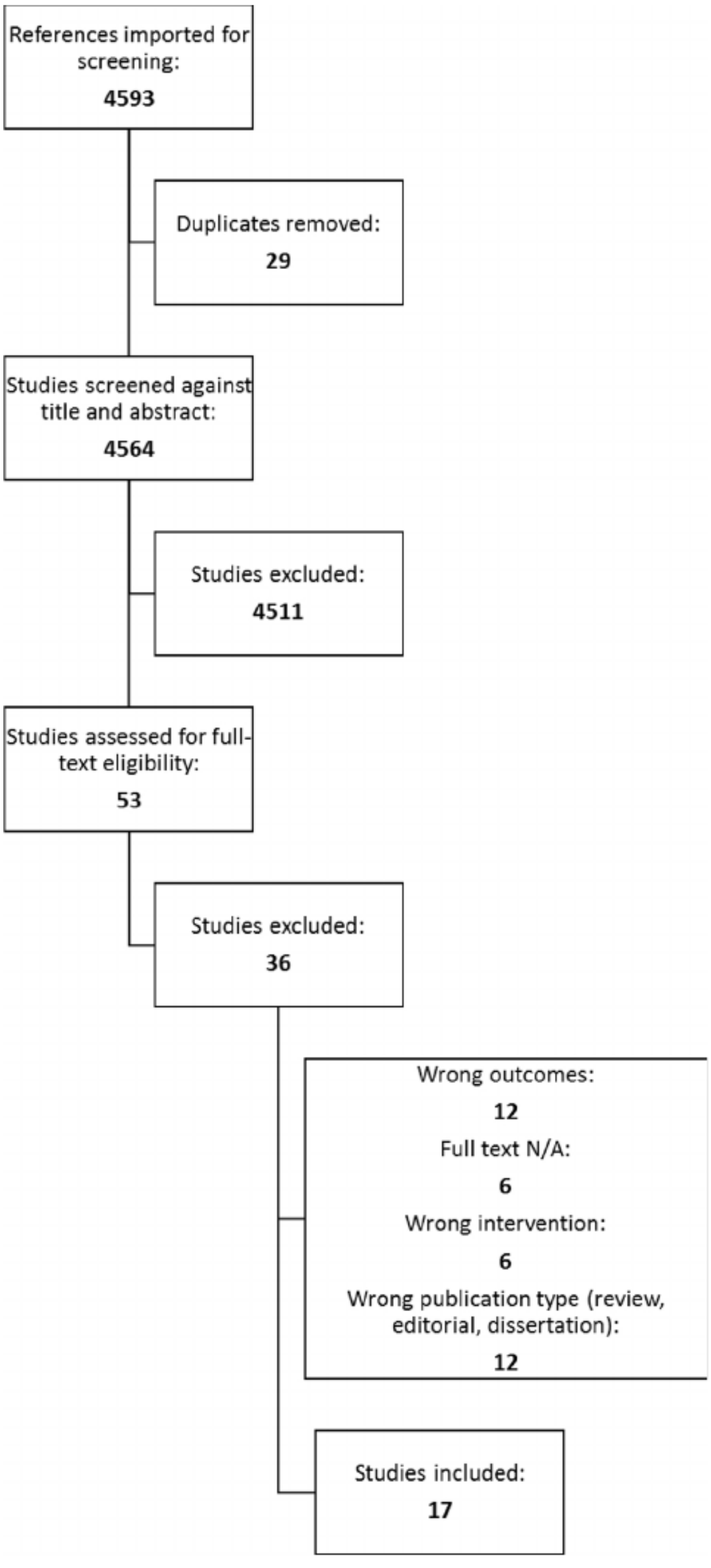

Fig. 1. PRISMA guidance flow diagram of identification, screening, and inclusion of eligible studies.

2.2.2. Exclusion criteria

Studies were excluded from the review according to the following a priori criteria: i) commentary manuscripts; ii) literature reviews; iii) dissertations; iv) studies that used qualitative analysis, and v) studies which did not investigate the relationship between mindfulness and road safety.

2.3. Information sources and search

An electronic search of databases from the disciplines of public health, psychology and transport safety (Ovid Cochrane Library, Ovid PsycINFO, Ovid EMBASE, CINAHL PLUS, Ovid TRANSPORT and TRID: TRIS and ITRD database) was conducted on February 7 th 2018 to locate studies from the first available year to February 2018. In addition, a bibliographic review of included studies and a review of gold set articles[1] was conducted to locate additional studies. Leading researchers in the field of mindfulness and road safety were also contacted to identify further relevant studies.

Two key concepts were selected: 1) mindfulness; and 2) road safety. Search terms (i.e., both indexed [e.g., Medical Subject Headings] and key words) associated with both concepts were derived independently from each author and in consultation with a subject matter expert librarian (see Table 1).

2.4. Study selection

Search results were exported into Endnote X8 software and duplicates were removed from the total number of identified records. Two researchers (SK, PH) independently completed an initial screening of titles and abstracts for eligibility and a priori inclusion and exclusion criteria were applied.

Following title and abstract screening, the two reviewers (SK, PH) independently applied inclusion and exclusion criteria to the full texts of the remaining articles to select studies for this review. A bibliographic review of included studies, as well as a review of gold set articles was conducted to identify additional relevant studies. Any conflicts between the two reviewers were resolved by a third reviewer (LB).

The primary outcome of interest was to identify whether mindfulness is associated with improved road safety. Road safety is largely concerned with methods of preventing road traffic injuries or fatalities among road users such as motorists, pedestrians, cyclists, and vehicle passengers (World Health Organization, 2018). This outcome was measured primarily via crashes or near-crashes, as identified through self-reports, crash records or driving simulator performance. Secondary outcomes of interest included aberrant driving behaviours (including speeding and texting while driving), as well as decrements in driving performance (i.e., such as errors) in a driving simulator.

2.5. Data collection process and data items

A full-text review of each included study was conducted by one reviewer (PH) and the following data items were extracted into a pre-tested data extraction sheet: study aim, study period, date of publication, study location and population, participant demographics, research design and method, recruitment, data sources and analysis, completion date, outcomes including crashes/near crashes, violations and driving performance, interventions, assessment of the risk of bias, salient findings and study limitations. Case-control studies were firstly reviewed, followed by observational cohort and cross-sectional studies. A second author (SK) reviewed the data extraction, and disagreements were resolved via consensus.

2.6. Quality of evidence

The quality of included studies was independently assessed by the two reviewers (SK, PH) using the National Heart, Lung and Blood Institute (NIH, 2014) study quality assessment tools. The NIH (2014) guidelines consider the following factors when critically evaluating a study's internal validity: risk of potential for selection bias, information bias, measurement bias or confounding factors – where the greater the risk of bias, the lower the quality rating of the study. A table was

[1] Gold set articles are relevant references identified before the development of a search strategy. These articles can then be used to help identify relevant search terms and to test that the search strategy will retrieve these items and other relevant references on your topic.

Table 1
Search strategy.

Database: Embase 1974 to 2017 February 7 th Search strategy:
1 exp car driving/
2 exp car driver/
3 exp motor vehicle/
4 1 or 2 or 3
5 mindfulness.ti,ab.
6 meditation.ti,ab.
7 distractibility.ti,ab.
8 (mental adj concentration).ti,ab.
9 (selective adj attention).ti,ab.
10 consciousness.ti,ab.
11 awareness.ti,ab.
12 alertness.ti,ab.
13 attention.ti,ab.
14 (text adj messaging).ti,ab.
15 5 or 6 or 7 or…14
16 traffic adj accident
17 15 AND 4
18 15 AND 16
19 15 AND 4 AND 16
20 15 AND (4 OR 16)

designed based on the 12 criteria for case-control studies and 14 criteria for observational cohort and cross-sectional studies. An overall quality rating (good, fair or poor) was then provided. Any conflicts between the two reviewers were resolved by a third reviewer (LB).

3. Results

3.1. Study selection

The review process from identification to inclusion of studies is summarised in Fig. 1 using the PRISMA flow chart. The combined searches identified 4593 articles. Twenty-nine duplicates were then removed. The titles and abstracts were screened for the remaining 4564 articles to determine if they meet the inclusion criteria outlined in 2.2.1 – where 4511 did not meet the criteria. The title and abstract screening identified 53 articles for full text review. Based on the full text review, 36 articles were excluded for the following reasons: 12 studies assessed the wrong outcomes, six examined the wrong intervention, 12 were identified as the wrong publication type (reports, dissertations, commentaries or reviews) and six did not have a full-text available. Altogether, 17 studies met the inclusion criteria and were assessed in the quantitative synthesis. A summary of included studies and their quality assessment ratings is shown in Table 2.

3.2. Study characteristics

Included studies were published between 2011 and 2017. There were five case-control studies and 12 cross-sectional studies. Of the cross-sectional studies, there were five experimental studies and seven retrospective self-report questionnaires. Details of each of the included studies are summarised in Table 2. Study sample sizes ranged from 10 to 955 with a mean of 55.7% women (range of means: 31–100%) and mean of 45.0% males (range of means: 0–69%). The mean age of participants was 29.3 years (range of means: 19–46). Samples were selected from a diverse range of settings including universities (Abdul Hanan et al., 2013; Feldman et al., 2011; Geden and Feng, 2015; Lin et al., 2016 Panek et al., 2015; Terry and Terry, 2015; Yanko and Spalek, 2014), laboratories (Berthié et al., 2015) and hospitals (Galéra et al., 2012; Gil-Jardiné, Née, Lagarde, Schooler, Contrand, Orriols, & Galéra 2017). Studies were also conducted in various countries including the U.S. (n = 6), France (n = 3), New Zealand (n = 3), Malaysia (n = 1), Taiwan (n = 1), Netherlands (n = 1), China (n = 1) and Canada (n = 1).

Nine studies examined the impact of mind-wandering on driving performance (Berthié et al., 2015; Burdett et al., 2016; Geden and Feng, 2015; Lin et al., 2016; Qu et al., 2015; Yanko and Spalek, 2014; Galéra et al., 2012; Gil-Jardiné et al., 2017; He et al., 2011). Three studies investigated the effect of distracted driving behaviours such as texting while driving (Feldman, et al., 2011; Panek, et al., 2015; Terry and Terry, 2015) and related internal/external distractions (Martens and Brouwer, 2013), dangerous driving behaviours (Qu, et al., 2015), inattentional blindness (Charlton and Starkey, 2013) and proceduralised or automatic driving (Charlton and Starkey, 2011) on driving performance and frequency of crashes. One study tested an intervention, specifically a Buddhist psychology course which incorporated Eastern practices of mindfulness and concentration (Kass et al., 2011). Primary outcome measures related to driving performance included compliance with speed limits and traffic signals (Abdul Hanan et al., 2013), reaction time to sudden events (Charlton and Starkey, 2011), frequency of driving violations and lapses (Burdett et al., 2016), frequency of crashes and responsibility for a crash (Galéra et al., 2012) as well as risky driving behaviours such as aggressive driving or drunk driving (Qu et al., 2015).

3.3. Risk of bias within studies

Ten studies were rated as 'good', five were rated as 'fair' and two were rated as 'poor' using the NIH (2014) guidelines. Several potential sources of bias were identified. For all case-control studies, there was no use of concurrent controls and only one study reported that assessors of exposure/risk were blinded to the case or control status of participants (Galéra et al., 2012). Most studies relied on self-reported levels of mindfulness and driving behaviour which may have resulted in over- or underreporting of actual behaviour due to recall errors or social desirability (Panek et al., 2015). This is particularly likely for disclosure of risky driving behaviours such as mind-wandering, texting while driving or experiences of actual or near-crashes as well as studies examining automatic driving behaviours such as when participants are required to report on how frequently they engage in an activity without awareness of it (Berthié et al., 2015). Asking individuals to recall mind-wandering episodes may also prompt them to think of such off-task thoughts and contribute to an artificial increase in the frequency of mind wandering episodes reported (Berthié et al., 2015).

Additionally, the samples used across various studies may not have been representative of the general population of drivers. For instance, Feldman et al., 2011 had an all-female sample which did not account for potential gender differences in the frequency of mind-wandering or texting-while-driving. Additional limitations include the use of broad age ranges with an uneven distribution of data in the very young and very old age groups, disenabling meaningful analysis of subgroups (Burdett, et al., 2016). There was also reliance on highly selective samples such as college students (Kass et al., 2011; Lin et al., 2016) or relatively inexperienced drivers (Terry and Terry, 2015).

3.4. Results of studies

3.4.1. Mindfulness and driving performance

One case-control study (Kass et al., 2011) investigated the effects of a mindfulness intervention on driving performance measures including number of traffic miscues and situation awareness. The authors found that students who completed the mindfulness intervention (i.e., were enrolled in a Buddhist psychology course) scored highly on a test of concentration - although concentration scores did not significant differ from those in the control group. The study's quality assessment rating was 'poor' due to several factors that intensified risk of bias including: lack of sample size justification, omission of inclusion and exclusion criteria and use of exposure measures that were not clearly defined and for which there was insufficient evidence of reliability and validity.

Several high-quality studies focused on the impact of mindfulness-related factors such as proceduralised "driving without awareness"

Table 2
Summary Characteristics and Quality Assessments of Included Studies.

Study	Study Design	Comparison Group	Intervention Group	Study Period	Study Setting - Country	Study Population	*N* (participants)	Gender (%)	*M* Age (SD, Range)	Outcome Measures	Summary of Key Findings	NIH Quality Assessment
Abdul Hanan et al. (2013)	Retrospective self-report questionnaire	No	No	NR	Malaysia	Staff & students at University Utara Malaysia	210	40% Male, 60% Female	19+ years *M* = NR (SD = NR, Range = NR).	Compliance with speed limit in school zones - any occasion where Ps were travelling at or below speed limit of 30 km/hour in school zone on school day.	Attitude, subjective norm, perceived behavioural control & habits were sig predictors of intention to comply & more confidence in their control of their speed were more likely to report intention to comply. Mindfulness was not a predictor in final model.	Poor
Berthié et al. (2015)	Retrospective self-report questionnaire	No	No	5 months	France	Students & personal contacts of the CLLE-LTC lab searchers.	191	NR	*M* = 36.6 (SD = 10.8, Range = 20 – 68).	1) Impact of mind-wandering duration on personal factors (driving practice) & contextual factors (goal of the trip, type of road, number of passengers). 2) Perceived consequences of mind-wandering on driving.	Mind-wandering affected 85.2% of Ps, who spent an average of 34.74% of trip in mind-wandering state. Contexts which favoured mind-wandering = situations in which less of Ps' attention needed to drive (e.g., familiar commutes, monotonous motorways or by-passes, Ps alone in vehicle).	Good
Burdett et al. (2016)	Retrospective self-report questionnaire	No	No	NR	New Zealand	Licensed drivers	552	20% Male, 80% Female.	NR	Frequency of reported mind-wandering.	All Ps reported mind-wandering during driving at least some of the time. Mind-wandering more likely to be reported on familiar roads than on unfamiliar roads, or when Ps are tired. Ps who reported relatively more mind-wandering were younger, reported less mindful attention in daily life, more cognitive failures, more driving violations & lapses.	Good
Charlton and Starkey (2011)	Case-control study	Casual group: Participated for single experimental session.	Expert group: Participated in driving simulator regularly over 3 months.	3 months	New Zealand	Licensed drivers	Casual group: 12. Expert group: 9.	Casual group: 42% Male, 58% Female. Expert group: 44% Male, 56% Female.	Casual group: *M* = 25.8 (SD = 8.4, Range = 20-50). Expert group: *M* = 31.3 (SD = 11.8, Range = 20-50).	Driving performance, vehicle detection, perceptual speed regulation, hazard reactions.	Speed & lane position variability quickly decreased with practice, as did Ps' subjective experiences of driving difficulty. Performance on embedded detection task appeared to become proceduralised part of driving task.	Good
Charlton and Starkey (2013)	Experimental study	Control group: experienced two of the same road	Practice group: repeatedly drove in single road in driving	3 months	New Zealand	Licensed drivers	Practice group: 29 Control group: 30	Practice group: 45% Male, 55% Female.	Practice group: *M* = 30.2 (SD = 11.5, Range = 17-49).	Inattention blindness and detection of changes to	Changes in what drivers reported noticing indicative of inattention blindness, & declining ratings of mental	Good

(*continued on next page*)

Table 2 (*continued*)

Study	Study Design	Comparison Group	Intervention Group	Study Period	Study Setting - Country	Study Population	*N* (participants)	Gender (%)	*M* Age (SD, Range)	Outcome Measures	Summary of Key Findings	NIH Quality Assessment
		scenarios in single session	simulator for 20 sessions spread over 3 months					Control group 47% Male, 53% Female	Control group: *M* = 32.3 (SD = 10.9, Range = 18-53).	driving environment (dependent on effects of extended practice) Driving difficulty ratings, vehicle speed and lane position	demand suggesting that many Ps were "driving without awareness". Extended practice resulted in increased sensitivity for detecting changes to road features associated with vehicle guidance & improved performance on an embedded vehicle detection task (detection of specific vehicle type).	
Feldman et al. (2011)	Retrospective self-report questionnaire	No	N/A	NR	USA	Undergraduate students. Ps excluded if: do not own phone capable of sending text messages; reported not driving; not having driver's license; or access to a vehicle at any point in the year.	231	100% Female.	*M* = 19.74 (SD = 2.27, Range = NR).	Frequency of texting while driving.	Ps lower in mindfulness reported more frequent texting-while-driving. Relationship mediated by emotion-regulation motives.	Good
Galéra et al. (2012)	Case-control study	Controls: Drivers not responsible for crash	Cases: Drivers responsible for crash	NR	France	Patients admitted to emergency department in previous 72 hours for injury sustained in a road traffic crash, aged 18 years or older, drivers, able to answer the interviewer (Glasgow coma score 15 at time of interview)	Cases: 453 Controls: 502	Cases: 63% Male, 37% Female Controls: 59% Male, 41% Female	18+ years M = NR (SD = NR, Range = NR).	Responsibility for crash: using standardised method adapted from Robertson & Drummer crash responsibility instrument. External distraction, negative affect, alcohol use, psychotropic drug use, & sleep deprivation.	Intense mind-wandering (highly disrupting/distracting content) associated with responsibility for a crash.	Good
Geden and Feng (2015)	Experimental study	Low perceptual load condition: Drive with no traffic, intersections or buildings present.	High perceptual load condition: Same road elements as low perceptual load conditions, with trees throughout the drive, eight houses, 30 incoming vehicles, three 2-way stop intersections	NR	USA	Undergraduate students	29	69% Male, 31% Female	*M* = 20.2 (SD = 5.7, Range = NR).	Frequency of mind-wandering.	High frequency of mind-wandering in low perceptual load condition. Impacts of mind-wandering on driving were found in reaction time, with task-unrelated thought having a longer time to respond.	Fair
	Case-control study	Controls: Drivers not		March 2013-	France	Patients admitted to Emergency	Controls: 514 Cases: 440	Controls: 62% Male,	Total: *M* = 38.0 (SD = 15,	Responsibility for crash: using	While strongly correlated, mind-wandering state & trait	Good

(*continued on next page*)

Table 2 (*continued*)

Study	Study Design	Comparison Group	Intervention Group	Study Period	Study Setting - Country	Study Population	*N* (participants)	Gender (%)	*M* Age (SD, Range)	Outcome Measures	Summary of Key Findings	NIH Quality Assessment
Gil-Jardiné et al. (2017)		responsible for crash	Cases: Drivers responsible for crash	January 2015		Department in first 24 hours after a crash. Eligible: Aged 18+; able to answer the interviewer (speaking French), with "Glasgow coma score of 15 when interviewed".		38% Female Controls: 60% Male, 40% Female	Range = NR). Controls: *M* = NR (SD = NR, Range = NR). Cases: *M* = NR (SD = NR, Range = NR).	standardised method adapted from Robertson & Drummer crash responsibility instrument.	were independently associated with responsibility for a crash.	
He et al. (2011)	Experimental study	Control group: Driving in no-wind conditions (condition that produced fewer episodes of mind-wandering).	Experimental group: Driving in heavy-wind conditions (conditions that placed heavier demands on attention).	NR	USA	Licensed drivers with at least 4 years of experience	18	39% Male, 61% Female	*M* = 22.0 years (SD = 3.3, Range = NR)	Performance & attentional changes during driving. Vehicle control, eye movement.	Compared with their attentive performance, participants showed few deficits in vehicle control while mind-wandering but tended to focus visual attention narrowly on the road ahead.	Fair
Kass et al. (2011)	Experimental study	Control group: Students in human factors psychology course	Experimental group: Students in Buddhist psychology course	15 weeks	USA	Control group: Students in human factors psychology course. Experimental group: Students in Buddhist psychology course.	Total: 16 Control:8 Experimental: 8	Total: 50% Male, 50% Female. Control group: 27% Male, 63% Female. Experimental group: 27% Male, 63% Female.	Total: *M* = 24.9 (SD = 4.7, Range 21-38). *Control M* = NR (SD = NR, Range = NR). *Experimental: M* = NR (SD = NR, Range = NR).	Driving performance (measured by number of traffic miscues). Situation awareness (measured using query method in driving simulator).	Mindfulness & concentration levels both sig related to situation awareness for driving.	Poor
Lin et al. (2016)	Experimental study	No	No	NR	Taiwan	Undergraduate & graduate students with driving licenses.	10	NR	NR	Mind-wandering (measured by changes in EEG activity).	Depriving Ps of salient sensory information imposes a relatively more perceptually-demanding task, leading to stronger activation in task-positive networks. When driver motion feedback is available, Ps may rely on vehicle motion to perceive perturbations which frees attentional capacity & tends to activate the default mode network.	Good
Martens and Brouwer (2013)	Experimental study	Controls group: Ps drove without any additional tasks/ distractions.	Experimental group 1: internal cognitive process as distraction. Experimental Group 2: External distraction group - sound &	NR	Netherlands	Licensed drivers	Total: 60 Control: 20 Experimental group 1: 20 Experimental group 2: 20	Control group: 70% Males 30% Females Experimental group 1: 65% Males, 35% Females. Experimetal group 2: 55% Males, 45% Females.	Control group: *M* = 47.5 (SD = NR, Range = NR) Experimental group 1: *M* = 43.5. (SD = NR, Range = NR). Experimental group 2: *M* =	Driving behaviour & physiological data.	Effects of internal & external distraction task reflected in speed, number of lane changes, deceleration, glances, subjective ratings. When effect found for both internal & external distraction task, results indicated similar negative effects. P reported indicated feeling less	Fair

(*continued on next page*)

Table 2 (*continued*)

Study	Study Design	Comparison Group	Intervention Group	Study Period	Study Setting - Country	Study Population	*N* (participants)	Gender (%)	*M* Age (SD, Range)	Outcome Measures	Summary of Key Findings	NIH Quality Assessment
			speech task as distraction.						47.1 (SD = NR, Range = NR).		involved in driving task with both secondary tasks.	
Panek et al. (2015)	Retrospective self-report study	No	N/A	NR	USA	Group 1: College students in undergraduate communications class Group 2: General adult population	Group 1: 313 Group 2: 612	Total: 43% Male, 57% Female Group 1: NR. Group 2: NR.	Total: *M* = 28.9 (SD = 12.3, Range = NR). Group 1: *M* = NR (SD = NR, Range = NR). Group 2: *M* = NR (SD = NR, Range = NR).	Dangerous texting behaviour: while walking or driving	Texting automaticity, trait self-control, 'acting with awareness' facet of trait mindfulness were uniquely predictive of texting while driving & texting while walking. Texting automaticity more strongly related to frequency of texting while walking than driving.	Good
Qu et al. (2015)	Retrospective self-report study	No	No	N/A	China	Ps with driving licence, > 1 year of driving experience.	310	48% Males, 52% Females	19+ years *M* = NR (SD = NR, Range = 19-55).	Dangerous driving behaviour (measured by Dula Dangerous Driving Index).	Frequency of mind wandering positively correlated with risky driving, aggressive driving, negative cognitive/emotional driving, & drunk driving. Mind wandering positively correlated with self-reported crashes, penalty points & fines. In high mind wandering Ps, males reported more risky & negative emotional driving behaviours than females. Males reported more penalty points & fines, but were involved in fewer crashes than females.	Fair
Terry and Terry (2015)	Retrospective self-report study	No	No	NR	USA	College students with driver's licence	385	52% Males, 48% Females	*M* = 19.0 (SD = 1.2, Range = NR).	Frequency of near-crashes related to cell phone use while driving (measured with CPWD questionnaire).	Ps who reported talking/textng on phone more frequently while driving had higher incidence of near-crashes related to each behaviour. After controlling for CPWD, multiple regression analysis indicated Ps who reported experiencing more phone-related intrusive thoughts also experienced more near-crashes. Two facets of mindfulness (acting with awareness & nonjudging of inner experience) negatively associated with near-crashes.	Good
Yanko and Spalek (2014)	Experimental study	No	No	N/A	Canada	Undergraduate students	Exp 1 = 17 Exp 2 = 32	NR	*M* = NR (SD = NR, Range = NR).	Exp 1: Braking reaction time, velocity, headway distance. Exp 2: same as Exp 1 + peripheral reaction time.	When mind-wandering, Ps: a) had longer response times to sudden events, b) drove at a higher velocity, c) maintained shorter headway distance, compared to when 'on-task'.	Fair

(Charlton and Starkey, 2011, 2013). This occurs when aspects of driving become automated or less difficult with practice and drivers lose conscious attention of their driving environment as if they were performing on 'autopilot' (Ranney, 1994). In one case-control study within a driving simulator (Charlton and Starkey, 2011), driving skills such as speed and lane position variability showed reductions with practice as participants perceived less driving difficulty. Performance on a detection task also became more proceduralised with practice. Charlton and Starkey (2013) found inattention blindness or driving without awareness were reported in situations requiring less 'mental demand'. However, extended practice was associated with increased sensitivity for detecting changes to road features and the detection of specific vehicle types.

3.4.2. Mindfulness and driving-related factors

A retrospective self-report study (Abdul Hanan et al., 2013) examined whether mindfulness was a significant predictor of intention to comply with the speed limit in school zones. Mindfulness was not a significant predictor in the final model, however the study's quality was assessed as 'poor' due to several 'fatal flaws' that increased the risk of bias including: lack of control for potential confounding variables and lack of detail to clearly describe the study population and exposure and outcome measures.

Three studies focused on the association between levels of mindfulness and texting while driving (Feldman et al., 2011; Panek et al., 2015; Terry and Terry, 2015). The predictive ability of mindfulness, specifically the 'acting with awareness' and 'nonjudging of inner experience' facets of mindfulness were explored in relation to texting while driving as well as the incidence of near-crashes. Results showed that individuals with lower self-reported levels of mindfulness, including the 'acting with awareness' and 'nonjudging of inner experience' facets of mindfulness, reported more frequent texting while driving (Feldman et al., 2011; Panek et al., 2015) and greater likelihood of reporting near-crashes (Terry and Terry, 2015). The quality assessment rating for these three studies was 'good' as study populations and exposure and outcome measures were clearly defined and sufficient evidence was provided for the accuracy and reliability of tools used.

A case-control driving simulator study (Martens and Brouwer, 2013) examined the effects of internal distractions, including cognitive processes, as well as external distractions, such as sound and speech, on driving behaviour. Results showed that internal and external distraction had a negative effect on driving performance factors including speed, number of lane changes and deceleration, reducing participants' involvement in the driving task.

3.4.3. Mind-wandering and driving-related factors

The occurrence of mind-wandering was frequently reported in several studies (Berthié et al., 2015; Burdett et al., 2016). In one study (Berthié et al., 2015), 85.2 percent of drivers reported that they experienced mind-wandering during driving and spent an average of 34.7 percent of their trips in a mind-wandering state.

Two studies (Galéra et al., 2012; Gil-Jardiné, et al., 2017) were case-control studies and assessed the relationship between mind-wandering and the likelihood of being responsible for a motor vehicle crash. Drivers who were considered to have any degree of responsibility for the crash were cases whereas drivers who were assessed as not responsible were controls. Results showed that intense mind-wandering involving disrupting or distracting content was associated with the likelihood of being responsible for a crash. The quality of both studies was assessed as 'good'. Both studies measured and accounted for potential confounding variables in their statistical analyses and measures of exposure/risk. In addition, Galéra et al., 2012 blinded assessors to the case/control status of participants.

The remaining studies were six retrospective self-report questionnaires and two experimental studies (Geden and Feng, 2015; Lin et al., 2016). Three studies (Berthié et al., 2015; Burdett et al., 2016; Geden and Feng, 2015) examined whether there was an association between contextual factors of a driving trip (i.e., purpose of trip, type of road selected, number of passengers) and the frequency and duration of mind-wandering. Results showed mind wandering occurred most frequently in situations associated with low attentional demands including familiar commutes, monotonous motorways or on 'plain drives' when few traffic intersections or buildings were present (Berthié et al., 2015; Geden and Feng, 2015). Younger-aged drivers who reported less mindful attention in their daily lives engaged in mind-wandering more frequently (Burdett, et al., 2016).

Driving performance outcomes such as reaction time and vehicle control, risky or aggressive driving behaviours and rate of reported crashes were also measured (Geden and Feng, 2015; Qu, et al., 2015; Yanko and Spalek, 2014; He, et al., 2011). Increased mind-wandering was associated with longer reaction times to sudden events (Geden and Feng, 2015; Yanko and Spalek, 2014), greater deficits in vehicle control (He, et al., 2011) and more risky and aggressive driving behaviour, driving violations and lapses (Burdett et al., 2016), negative cognitive or emotional driving, drunk driving and self-reported crashes, penalty points and fines (Qu et al., 2015). For four studies (Geden and Feng, 2015; Qu et al., 2015; Yanko and Spalek, 2014; He et al., 2011), the quality assessment rating was 'fair' - as although there was no evidence of a 'fatal flaw', several of these studies did not control for key potential confounding variables and the study population was not clearly specified and defined. The remaining two studies were assessed as 'good' (Berthié et al., 2015; Burdett et al., 2016). There was evidence provided for the validity and reliability of exposure and outcome measures and statistical analyses accounted for the role of potential confounding variables on the relationship between exposures and outcomes.

4. Discussion

4.1. Summary of evidence

This systematic review examined 17 studies (12 cross-sectional and 5 case-control) published between 2011 and 2017 that focused on the association between mindfulness or mind-wandering on road safety measures including driving performance (vehicle control, reaction time), compliance with speed zones and traffic signals, near-crash and crash rates, as well as propensity to engage in distracted driving behaviours. Overall, the findings of the review suggest that mind-wandering tends to occur in driving situations with low attentional demands, there is an association between reduced mindfulness and more frequent texting while driving, and limited studies have specifically explored the effectiveness of mindfulness-based intervention to improve road safety. These findings are explored in more detail below.

The key findings are as follows: the fair to high quality ratings for the studies examining the effect of mind-wandering on driving-related factors support the phenomenon of more mind-wandering occurring in driving situations that place a low attentional demand on the driver (Berthié et al., 2015; Geden and Feng, 2015). Additionally, there is increasing evidence from electrophysiological and neuropsychological studies that show changes in large-scale brain networks during mind-wandering which provide further evidence on their influence on driving performance (Galéra et al., 2012). For instance, Lin, et al. (2016) used electroencephalographic sources to identify greater mind-wandering under low perceptual demands during driving, as indicated by shifts in brain activity. Given the considerable evidence showing that mind-wandering reduces drivers' active attention and may result in proceduralised driving, it is likely to have negative effects on core driving skills such as speed, lane position variability and vehicle control (Geden and Feng, 2015; He et al., 2011).

There were particularly salient findings related to the association between reduced mindfulness and more frequent texting while driving (Feldman et al., 2011; Panek et al., 2015; Terry and Terry, 2015). There is evidence that this relationship may be mediated by emotion-

regulation and attention-regulation motives. For instance, individuals may use text-messaging more frequently as a way of reducing unpleasant emotions while driving or refrain from texting in order to focus greater attention on present-moment experiences (Feldman et al., 2011). Based on the studies included in this review, mind-wandering is also likely to increase an individual's involvement in motor vehicle crashes (Galéra et al., 2012; Gil-Jardiné et al., 2017) due to the driver's tendency to overlook hazards or commit more errors while driving (Galéra et al., 2012).

As a result of the limited and low-quality evidence related to mindfulness-based interventions, few conclusions can be drawn regarding the applicability of mindfulness techniques for training programs or related interventions. The single study which evaluated mindfulness training (Kass et al., 2011) was also restricted by the short duration of driving simulation and it is probable that mindfulness may have a larger influence on driving performance than was captured. However, a prominent finding was that measures of concentration and mindfulness need to be distinguished when designing targeted training programs to improve driver safety. There were recommendations that brief mindfulness exercises before or while driving may reduce affective or cognitive predictors of texting while driving although further research is needed to determine the feasibility, desirability and effectiveness of these interventions.

Taken together, it appears that more research is warranted to understand the relationships between mindfulness and safer driving practices. While the focus of current literature has been on distraction, primarily texting, the outcomes suggest associations exist between mindfulness and other behavioural outcomes: deliberate speed violations; aggression and crash outcomes.

4.2. Strengths and limitations

It should be noted that mindfulness was defined and measured in many different ways across the studies in this systematic review - making it difficult to determine its usefulness as an intervention for improving road safety. For example, some studies defined mindfulness narrowly (e.g., attention, mind-wandering, etc.), while others defined it more broadly (e.g., involving attention and attitudinal aspects such as 'non-judging, etc.'). Another limitation of several studies was the reliance on self-report measures of mindfulness levels and events involving aberrant or distracted driving behaviour. This may be particularly problematic for automatic behaviours such as texting while driving that require participants to have retrospective awareness of their behaviour (Panek et al., 2015). Lack of awareness could account for a pattern observed in previous studies which point to underreporting frequency of mobile phone use (Boase and Ling, 2013). Retrospective self-reports of mind-wandering could also be impacted by desirability bias towards the researchers (Galéra et al., 2012). Additionally, most studies were cross-sectional which limits the ability to draw inferences regarding temporal relationships between variables (Feldman et al., 2011). It should also be noted that several studies had unrepresentative samples (e.g., all female participants, all college student participants, Feldman et al., 2011; Terry and Terry, 2015) which means that these findings may not be applicable to the general population. Another consideration is that several studies measured driving behaviour in a simulated environment which may not generalise to real-world driving (Geden and Feng, 2015).

4.3. Conclusions

Mindfulness has been identified as a potentially effective intervention for enhancing road safety, however mindfulness is defined and measured in many different ways which makes it difficult to determine its usefulness as an intervention for reducing road trauma. Based on a wider review of the literature, there is a rationale supporting the development of capabilities such as attention and emotional regulation cultivated through mindfulness-based interventions for improving driver behaviour and performance. However, here is a paucity of studies on mindfulness-based interventions for improving driver behaviour and performance. More research is warranted to determine whether mindfulness interventions are effective in reducing other aberrant or dangerous driving behaviours, and therefore reducing road trauma.

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