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A meta-analysis of the effects of texting on driving

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ABSTRACT

Text messaging while driving is considered dangerous and known to produce injuries and fatalities. However, the effects of text messaging on driving performance have not been synthesized or summarily estimated. All available experimental studies that measured the effects of text messaging on driving were identified through database searches using variants of "driving" and "texting" without restriction on year of publication through March 2014. Of the 1476 abstracts reviewed, 82 met general inclusion criteria. Of these, 28 studies were found to sufficiently compare reading or typing text messages while driving with a control or baseline condition. Independent variables (text-messaging tasks) were coded as typing, reading, or a combination of both. Dependent variables included eye movements, stimulus detection, reaction time, collisions, lane positioning, speed and headway. Statistics were extracted from studies to compute effect sizes (r_c). A total sample of 977 participants from 28 experimental studies yielded 234 effect size estimates of the relationships among independent and dependent variables. Typing and reading text messages while driving adversely affected eye movements, stimulus detection, reaction time, collisions, lane positioning, speed and headway. Typing text messages alone produced similar decrements as typing and reading, whereas reading alone had smaller decrements over fewer dependent variables. Typing and reading text messages affects drivers' capability to adequately direct attention to the roadway, respond to important traffic events, control a vehicle within a lane and maintain speed and headway. This meta-analysis provides convergent evidence that texting compromises the safety of the driver, passengers and other road users. Combined efforts, including legislation, enforcement, blocking technologies, parent modeling, social media, social norms and education, will be required to prevent continued deaths and injuries from texting and driving.

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1. Introduction

Texting while driving has attracted considerable media attention and intense public interest. Media stories typically describe crashes that result in deaths or injuries of drivers who may have been texting at the time of a collision. For example, the pain and suffering of friends and family following texting-related crashes is shown in the video *One Minute to the Next* by Werner Herzog (New York Times, 2013). Other stories typically cite a well-known study that found drivers are 23 times more likely to crash while texting (Ritchell, 2009), drawing on work from the Virginia Tech. Transportation Institute (VTTI) who found that text messaging increased the odds of being involved in crash, near miss or incident for truck drivers (Olson et al., 2009).

Attention to this issue is justified. At any given time in the U.S., an estimated 1.0% (or 135,300) of all drivers are observed manipulating a handheld device, which includes texting and dialing (NHTSA, 2009). As a category of distraction, texting and driving is increasing. Year over year increases in text messaging while driving were related to increases in the number of fatalities in the Fatality Accident Reporting System (FARS, U.S.) from 2002 to 2007 (Wilson and Stimpson, 2010). Based on regression analysis, an estimated 16,141 *additional* fatalities resulted from texting while driving over this time period.

In 2011, distraction was a contributing factor in about 10% of all driver fatalities and 17% of injuries in the U.S. (NHTSA, 2013), with drivers 15–19 years of age representing the highest proportion of distracted drivers (WHO, 2011). Among U.S. high school students,

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45% reported texting and driving in 2012 (Olsen et al., 2013), which is an increase from 26% of 16 and 17 year olds in 2009 (Madden and Lenhart, 2009). In certain college samples, 92% of respondents reported reading texts while driving (Atchley et al., 2011). Of all adults in 2010 in the U.S., 31% said they have "sent or read a text while driving" (Centers of Disease Control and Prevention, 2011), while in Europe, the self-reported frequency of texting "regularly or fairly often" or "at least once" in the past 30 days ranged from approximately 15 to 31%.

Understanding the impact of texting on driving performance and, in turn, on traffic safety and public health, remains an important area of research. A number of studies have examined how texting adversely affects driving performance, with a modest body of experimental research involving driving simulation and on-road studies. The general consensus is that those drivers who look away from the road for prolonged periods of time do not control their vehicles sufficiently (Hosking et al., 2009; Owens et al., 2011). However, there has not yet been a thorough examination of the empirical research to expand on how texting affects the specific tasks necessary for safe driving, which driving behaviors are most adversely affected, how effects vary across studies and populations, and where changes might be implemented to reduce harm. Toward these ends, the aim of this meta-analysis is to systematically characterize the impact of reading and typing text messages on driving with the overarching goal of improving traffic safety.

2. Method

The format and content of this paper are in accord with the PRISMA meta-analysis guidelines including: title, structured abstract, introductory rationale, methods (i.e., information sources, selection strategy, inclusion criteria, coding, measures and statistics), results (i.e., synthesis and consideration of bias), discussion (i.e., summary, limitations and conclusions), and funding sources (Moher et al., 2009).

2.1. Data sources and search strategy

Using key word variants of "driving" and "text messaging" (e.g., driv*, messag*, text*, sms*), a number of databases were searched for studies without restriction on year of publication through January 2014, including Embase, PubMed, MEDLINE, and Web of Science. In addition, targeted journals (*Accident Analysis and Prevention*, *Human Factors*, *Traffic Injury Prevention*), conference proceedings (e.g., Human Factors and Ergonomics Society, Transportation Research Board, Driving Assessment), and government web sites (e.g., National Highway Traffic Safety Administration, NHTSA) were also searched for 'grey' literature (e.g., technical reports, proceedings papers). A backtracking or *ancestry* approach from reference sections was also used to identify additional studies.

2.2. Study selection

The selection of studies for inclusion in the meta-analysis is illustrated in Fig. 1. Abstracts returned from searches and backtracking (N = 1476) were screened by applying general criteria that a study must focus on text messaging and driving. Complete publications (n = 82) were further analysed to determine whether a study met the a priori criteria for inclusion. First, a study had to measure driving performance, which was defined as controlling a vehicle, simulation or proxy task. Second, study participants had to be driving and reading or writing text messages compared to a baseline or control condition. Texting was defined as reading and/or typing messages as well as associated device manipulation and interface

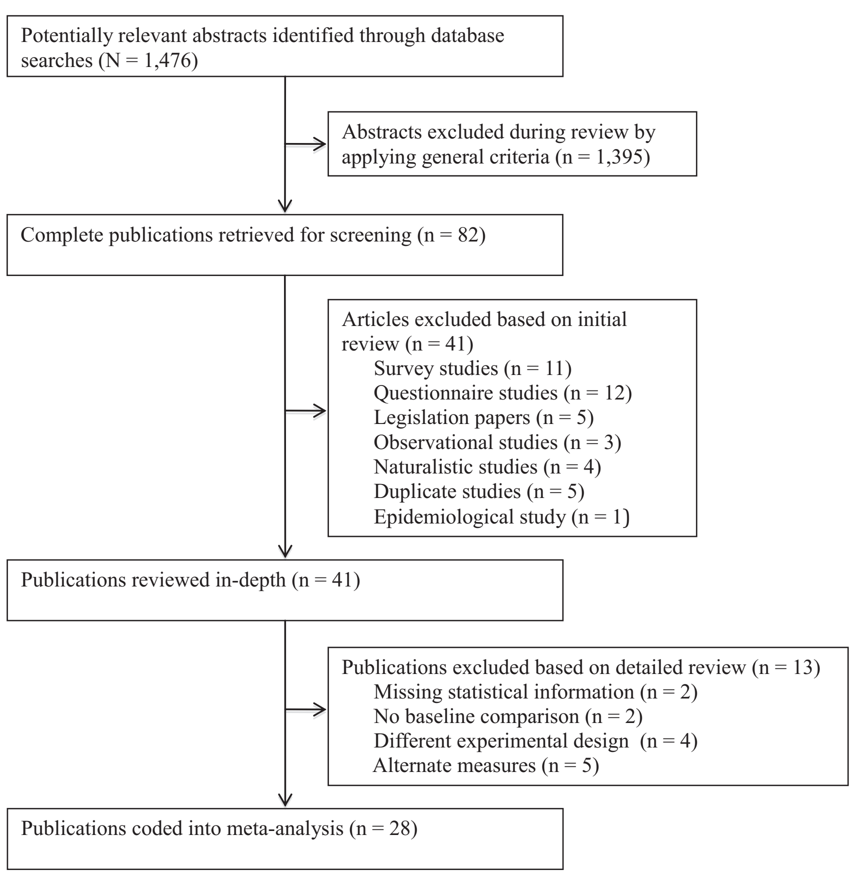

Fig. 1. Search flow and selection of publications included in the meta-analysis.

interaction. Careful review led to the exclusion of an additional 41 papers based on these criteria. Excluded studies typically used non-experimental methods including survey, policy analysis, questionnaire and observational methods. Five technical reports that were duplicates of published papers were also excluded.

The 41 remaining studies were examined in-depth. An additional six studies were excluded because experimental designs did not include a baseline or control condition or used an alternate experimental design. Five studies used measures other than driving performance (e.g., physiological indicators). Two studies were excluded due to insufficient statistical information, although the authors were contacted several times with requests to provide missing information. A total of 28 studies were included in the meta-analysis.

2.3. Data extraction and coding

Common dependent variable measures of driving performance have evolved over decades of research on driving (Elvik and Vaa, 2004; Evans, 2004; Shinar, 2007). Specifically, the capability of drivers to respond to hazards or emergency events (eye movements, detection, reaction time [RT], and collisions), lane keeping (lateral lane positioning), speed maintenance (speed, speed variance) and car following (headway, headway variance) are four such fundamental driving tasks. Within these task categories, variants of each of these measures were coded from identified studies. The operational definitions of specific measures can be found in prior literature (Caird and Horrey, 2011).

The independent variables of texting task included typing (Type), reading (Read), and both typing and reading (Type/Read). The length of text messages (whether read, typed or both) was also coded into the categories of one-word, long answer and copy task. Long answer responses required multiple texting interactions, whereas copy and one-word tasks were more discrete tasks. Two of the authors (KJ, JKC) extracted measures from studies and two authors (KJ, CRW) reconciled coding discrepancies through discussion.

Because individual studies could contribute more than one measure per category, multiple effect sizes from a study within a particular dependent variable category were averaged to avoid violating the independence of observations assumption, following Hunter and Schmidt's recommendations (2004, pp. 429–443). Statistical values (i.e., *F*, *t*, *p*, *M*, *SD*, *SE*) were extracted and converted to correlation effect sizes (r_{es}) (Rosenthal and DiMatteo, 2001). Between-subjects values were corrected for unequal group size (Rosnow et al., 2000). Authors were contacted to obtain unreported null results and a variety of other omitted values from the original studies. To complete the statistical conversions, *M* and *SD* were used wherever possible, and it is important to note that this approach typically yields *lower* r_{es} than using, for example, a *t*-value (Moser and Stevens, 1992). Thus, the meta-analytic results that we report likely reflect *conservative* estimates of the effects of texting on driving performance.

2.4. Statistical analysis

Effect sizes were computed for categories where at least three coefficients were available, which meets the recommended minimum (Hunter and Schmidt, 2004). Weighted mean effect sizes (r_c, *d*), 95% confidence intervals (CI) and 90% credibility intervals CrdI) were computed. *Confidence intervals* (CI) indicate the precision of the mean effect size. *Credibility intervals* (CrdI) are an estimate of generalizability, reflecting the range of effect sizes that likely contain any *specific* situation. The larger the CrdI, the more likely there

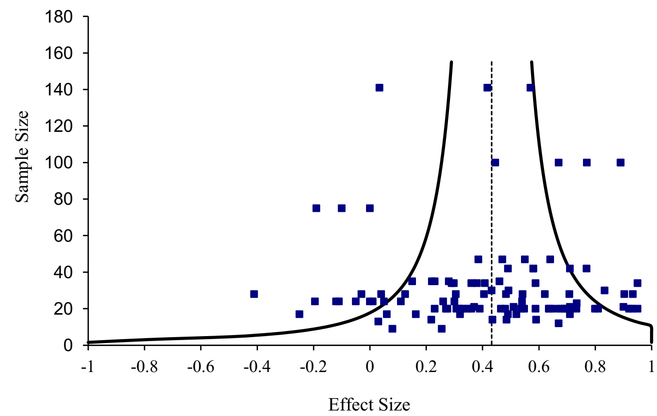

Fig. 2. Funnel plot of averaged effect sizes and associated sample sizes for all dependent measures. The overall mean effect size is represented by the dotted line.

are significant moderator effects, meaning that the strength of the effect sizes are dependent on these other factors.

3. Results

3.1. Study characteristics

Studies included in the meta-analysis are listed in Table 1, with the earliest located study conducted in 2004 and the most recent in March 2014. The number of studies on texting and driving has increased in the past three years from 5 in 2011, to 7 in 2012 and 8 in 2013. Most studies used driving simulators of various types ($N = 25$), whereas three were conducted on closed test tracks. Most studies were conducted in the U.S. ($N = 16$) followed by Europe and the Middle East (7), Australia (3) and Asia (2). A total of 977 participants constituted the overall sample of drivers. Driver age ranged from 16 to 64 with a mean of 26.2 years of age ($SD = 6.1$). The overall sample is representative of younger drivers who are likely to text and drive, but may also reflect convenience samples from universities. The combined sample had an approximately equal number of women (504) and men (473).

3.2. Quantitative results

To check for potential publication and related biases, a funnel plot of all averaged effect and corresponding sample sizes is shown in Fig. 2, which appears symmetrical. After visual inspection of the data (Egger et al., 1997), several follow-up statistical tests are suggested (Rothstein et al., 2006). The Eggers Linear Regression test was not significant ($R = 0.132$, $F(1, 104) = 1.837$, $p = 0.178$), which indicates minimal bias of effect sizes included in our meta-analysis (Sutton, 2009). In other words, there appears to be negligible publication bias, where the research process favors errant but significant results brought about through sampling error.

A total of 28 studies contributed 234 effects size entries to this meta-analysis, before within-study dependent variable averaging. Table 2 lists the number of effect sizes (*k*) combined to calculate the mean effect size, the number of participants (*N*), weighted mean effect sizes (i.e., r_c, *d*), confidence (CI) and credibility (CrdI) intervals. Subsequent results interpretation will focus on r_c as the summary statistic for the dependent variables of eye movements, detection, reaction time, collisions, lateral positioning, speed and headway.

3.2.1. Effects of Type/Read, Type and Read on dependent variables

Table 2 presents the effects of text messaging on the dependent variables. The tasks that drivers performed while driving were Type/Read, which is indicative of a driver who performs both

Table 1
Study authors, year of publication, experimental setting, participant characteristics, and independent and dependent variables.

Study	Pub. year	Setting	*N*	Ages and gender (SD)	Independent variables	Dependent variables
Alosco et al.	2012	Simulator	143*	Text: *N* = 45, *M* = 20.2 (2.2) Con.: *N* = 96, *M* = 19.9 (3.0) *T*: 34 F, 11 M; C: 55 F, 43 M	Read + Type v. Base.	Det., Coll., Lat.
Bendak	2013	Simulator	20	Ages: *M* = 22.1 (1.5) 20–25, M 20	Read + Type v. Base	Eye, Coll., Lat.
Basacik et al.	2011	Simulator	28	Ages: 18–25 M 14, F 14	Read, Type v. Base	Eye, RT, Lat., Long.
Bruge and Chaparro	2012	Simulator	20	Ages: *M* = 29.2 (13.9) 18–55, 10 M, 10 F	Read + Type v. Base.	Det., RT
Choi et al.	2013	Simulator	55	Ages: *M* = 24.0 (2.1) 28 M, 27 F	Read + Type v. Base.	Lat., Long.
Crandall and Chaparro	2012	Simulator	23	Ages: *M* = 27.0 (6.0) 18–40, 14 M, 9 F	Type v. Base.	Lat.
Crisler et al.	2008	Simulator	14	Ages: 18–22 7 M, 7 F	Read + Type v. Base. Type v. Base.	Lat., Long.
Drews et al.	2009	Simulator	20	Ages: *M* = 21.0, 19–23 20 M, 20 F (20 dyads)	Read, Type v. Base., Read + Type v. Base.	RT, Coll., Lat., Long.
He et al.	2013	Simulator	35	Ages: *M* = 21.7 (3.6) 10 M, 25 F	Read + Type v. Base.	RT, Lat., Long.
Hosking et al.	2009	Simulator	20	Ages: *M* = 19.1 (1.2) 18–21, 12 M, 8 F	Read, Type v. Base. Read + Type v. Base.	Eye, Det., RT, Lat., Long.
Kircher et al.	2004	Simulator	10	Ages: 24–35 7 M, 3 F	Read v. Base.	RT, Long.
Knapper et al.	2012	Simulator	19	Ages: *M* = 37 (9.8) 27–59, 14 M, 6 F	Type v. Base.	Eye, Lat., Long.
Libby et al.	2013	Simulator	20	Ages: *M* = 26.7 (8.8) 18–55, 11 M, 9 F	Read + Type v. Base.	Eye, Det., RT, Long.
Libby and Chaparro	2009	Simulator	34	Ages: *M* = 23.3 (8.9) 18–58, 5 M, 29 F	Read + Type v. Base.	Eye, RT, Lat., Long.
Long et al.	2012	Task Simulator	12	Ages: *M* = 24.2 (2.9) 8 M, 6 F	Read v. Base.	RT
McKeever et al.	2013	Simulator	28	Ages: *M* = 21.0 (2.4) 18–28, 16 M, 12 F	Read + Type v. Base.	Lat., Long.
Owens et al.	2011	Closed Test Track	20	Ages: *M* = 35 (12) 19–51; 11 M, 9 F	Read + Type v. Base.	Eye, Lat.
Ranney et al.	2011	Simulator	100	Ages: *M* = 42.7 (9.7) 25–64, 50 M, 50 F	Read + Type v. Base.	Eye, RT, Lat., Long.
Reed and Robbins	2008	Simulator	17	Ages: 18–25 8 M, 9 F	Read, Type v. Base. Read + Type v. Base.	RT, Lat., Long.
Rudin-Brown et al.	2013	Simulator	24	Ages: *M* = 33 (10) 25–50, 12 M, 12 F	Read, Read + Type v. Base.	Eye, Lat., Long.
Sawyer and Hancock	2013	Simulator	47	Ages: 18–34	Type v. Base.	RT, Lat., Long.
Stavrinos et al.	2013	Simulator	75	Ages: *M* = 21.1 (1.6) 16–25, 41 F, 34 M	Read + Type v. Base.	Coll., Lat., Long.
Thupa et al.	2014	Simulator	20	Ages: *M* = 27.4 (9.8) 4 F, 16 M	Read + Type v. Base.	Lat., Long.
Yager	2013	Closed Test Track	43	Ages: *M* = 29.5 (14.2) 16–63, 20 M, 23 F	Read, Type, Read + Type v. Base.	Det., RT
Yager et al.	2012	Closed Test Track	42	Ages: *M* = 35 (17.1) 16–54, 17 M, 25 F	Read, Type v. Base.	Det., RT, Lat.
Yan et al.	2014	Simulator	30	Ages: *M* = 24.1 (2.4) 11 F, 19 M	Read, Type v. Base.	RT
Yannis et al.	2014	Simulator	34	Ages: 18–28 19 M, 15 F	Read, Type v. Base.	RT, Coll., Long.
Young et al.	2014	Simulator	24	Ages: *M* = 33.4 (9.9) 25–50, 12 M, 12 F	Read, Type + Read v. Base.	Eye, Lat., Long.

Notes. *Pub.* is publication, *N* is number of participants, *M* is male, *F* is female, *Read* is reading a text message, *Read + Type* is reading and typing a text message, *Type* is typing a text message, *Base.* is a baseline or control condition, *RT* is reaction time (e.g., lead vehicle braking), *Lat.* is lateral control (e.g., standard deviation of lane position [SDLP], lane excursions, etc.), *Long.* is longitudinal control (e.g., speed, speed variance, time or distance headway), *Det.* is detection (e.g., secondary task), *Eye* is eye movement (e.g., eyes off road time, glance duration), and *Coll.* is number of collisions. *Between-subjects groups of texting and control. All other studies used within-subjects experimental designs.

typing and reading tasks interleaved with driving, and Type and Read, which are these same tasks measured separately.

Across dependent variables for all texting tasks, most effect sizes were moderate to large (Cohen, 1988; Lipsey and Wilson, 1993; Rosenthal and DiMatteo, 2001) with the exception of speed variance, which was negligible. Eye movement, RT, and lateral positioning effect sizes were larger for Type/Read and Type than for Read, which is consistent with the intensity of interaction required to do these tasks. Detection, collisions, speed and headway measures also had moderate to large effect sizes, but the 90% credibility intervals for these variables were wide indicating the presence of significant moderator variables.

3.2.2. *Effects of text length on performance*

Table 3 lists the effect sizes, confidence intervals and credibility intervals for text message length on RT, lateral control, speed and speed variance. For RT, one word ($r_c = 0.63$) and long answer ($r_c = 0.63$) texting tasks had larger effect sizes, whereas the copy task had a moderate effect size ($r_c = 0.26$). All three texting tasks produced variation in lateral control ($r_c = 0.35$, 0.38, 0.58).

Table 2
Meta-analyses of the effects of texting on driving dependent variables.

Variable	k	N	r_c	d	95% CI		90% CrdI	
					L	U	L	U
Eye movements								
Read vs. Baseline	5	116	0.60	1.48	.35	.86	.17	1.00
Type/Read vs. Baseline	4	98	0.74	2.18	.41	1.00	0.20	1.00
Type vs. Baseline	4	169	0.88	3.68	0.84	0.92	0.83	0.93
Detection								
Type/Read vs. Baseline	4	223	0.24	0.50	−0.09	0.58	−0.21	0.70
Reaction time								
Read vs. Baseline	7	160	0.47	1.07	0.29	0.60	0.16	0.79
Type/Read vs. Baseline	8	277	0.59	1.47	0.42	0.76	0.23	0.95
Type vs. Baseline	6	190	0.57	1.37	0.43	0.71	0.36	0.77
Collisions								
Type/Read vs. Baseline	5	286	0.32	0.68	0.03	0.62	−0.20	0.84
Lateral positioning								
Read vs. Baseline	7	175	0.32	0.67	0.18	0.52	−0.01	0.64
Type/Read vs. Baseline	11	515	0.37	0.79	0.25	0.50	0.11	0.64
Type vs. Baseline	10	260	0.50	1.16	0.39	0.62	0.33	0.67
Speed								
Type/Read vs. Baseline	12	311	0.32	0.67	0.22	0.47	0.00	0.64
Speed variance								
Type/Read vs. Baseline	8	249	0.06	0.12	−0.12	0.22	−0.23	0.33
Mean headway								
Type/Read vs. Baseline	5	192	0.53	0.07	0.36	0.70	0.28	0.79
Headway variance								
Type/Read vs. Baseline	6	220	0.59	1.45	0.45	0.73	0.36	0.82
Minimum headway								
Type/Read vs. Baseline	4	93	0.30	0.62	0.10	0.48	−0.01	0.61

Note: k = number of samples; N = total number of participants; r_c = weighted mean correlations corrected for reliability; d = Cohen's d-effect size transformed from r_c; CI = confidence interval; CrdI = credibility interval; Read indicates participants only received a text during the measure; Type/Read indicates that participants both received and sent a text during the measure; Type indicates participants only sent a text.

Speed reductions for one-word answers produced moderate effect sizes (r_c = 0.23), whereas long answer tasks were slightly larger (r_c = 0.34).

4. Discussion

This meta-analysis provides the first comprehensive understanding of the pattern of performance impairments resulting from texting and driving. Typing text messages while driving adversely affected nearly all aspects of safe driving performance. Specifically, drivers exhibited prolonged and frequent glances away from the road, missed more detection opportunities, had slower responses to hazards, were involved in a higher number of crashes and did not control their vehicles within the lane as accurately compared to baseline driving (i.e., when not texting). Typing and reading messages in combination produced similar effect sizes, indicating negative impacts on driving performance. Reading text messages resulted in relatively smaller effect size estimates versus typing, or reading and typing together, but negatively impacted driving performance nonetheless. Drivers who read and typed texts also tended to decrease their speed and increase the distance to vehicles in front of them, which partially compensated for impairments produced by looking away from the roadway.

Not looking at the road while reading and typing is a striking visual distraction problem—especially if a texting conversation ensues (i.e., more than one exchange). In this meta-analysis, the largest effect sizes were for eye movements during typing and reading (r_c = 0.74) and typing alone (r_c = 0.88). When drivers repeatedly glance away from the roadway to type and read text messages, detection of hazards, reaction time to events, collisions and vehicle control are also affected. One study showed that typing a simple text such as "I'm on my way home" took an average time of 37 s to complete while driving and, of this time, 26 s was spent looking away from the roadway (Owens et al., 2011). During this same

Table 3
Meta-analyses of the effects of text message length on dependent variables.

Variable	k	N	r_c	d	95% CI		90% CrdI	
					L	U	L	U
Reaction time								
One Word Answer	6	225	0.63	1.61	0.43	0.83	0.26	1.00
Long Answer Task	5	141	0.63	1.59	0.59	0.66	0.63	0.63
Copy Task	3	68	0.26	0.53	0.16	0.37	0.26	0.26
Lateral control								
One Word Answer	12	536	0.35	0.75	0.22	0.47	0.05	0.64
Long Answer Task	5	151	0.38	0.81	0.27	0.49	0.38	0.38
Copy Task	5	116	0.58	1.42	0.46	0.70	0.58	0.58
Speed								
One Word Answer	7	172	0.23	0.47	0.04	0.42	−0.03	0.50
Long Answer Task	3	89	0.34	0.71	−0.01	0.67	−0.05	0.73
Speed variance								
One Word Answer	6	163	−0.01	0.02	−0.20	0.19	−0.27	0.26

Note: k = number of samples; N = total number of participants; r_c = weighted mean correlations corrected for reliability; d = Cohen's d-effect size transformed from r_c; CI = confidence interval; CrdI = credibility interval.

span, drivers looked at their phones an average of 17.5 times and the longest average glance duration away from the roadway was 2.7 s. Glances away from the roadway that exceed 1.6–2.0 s are known to increase crash risk (Horrey and Wickens, 2007; Klauer et al., 2006; Simons-Morton et al., 2014).

In addition to visual distraction, texting while driving also produces physical driver distraction. Manipulation of a cell phone to text interferes with lateral vehicle control. Moderate to large effect sizes were found for increases in lateral variance while texting. One or two hands are typically used to type on a phone that is pinned to the steering wheel or held in one hand and this causes the frequency of steering wheel corrections to be reduced or delayed. Resulting corrections to lateral control often require large, fast course corrections that result in erratic vehicle movement, which may require other drivers to anticipate and accommodate (Owens et al., 2011).

Drivers appear to produce compensatory behavior while texting. Falling farther back from lead vehicles (increasing headway) and driving slower (reducing speed) partially compensates for redirecting attention away from the immediate traffic environment. However, prolonged and repeated glances to type text messages likely negate the additional time and distance that is gained through these adaptive behaviors due to not seeing important changes in the traffic environment. Whether drivers who are texting decrease speed and increase headway intentionally as a safety strategy or as a simple default for being distracted is debatable. Headway variance also increases while texting, suggesting that drivers intermittently follow lead vehicles, fall back and catch up again as texts are read, typed and sent. Drivers who follow texting drivers must anticipate and accommodate these longitudinal and lateral oscillations.

Overall, texting produces visual, physical and cognitive driver distraction. Drivers who have their eyes off the road, their hands off the steering wheel and their thoughts directed elsewhere are an active safety threat. Despite what some drivers may believe about their ability to multi-task or safely text while driving, the accumulated evidence thus far from epidemiologic, observational and experimental research on the safety of texting and driving is negative, unequivocal and convergent. In addition to the results of this meta-analysis, naturalistic studies (i.e., where drivers are using their own vehicles) have found increases in crash risk when texting and driving (Fitch et al., 2013; Klauer et al., 2014; Olson et al., 2009). Among the myriad of potential driver distractions, some researchers (GHSAb, 2013b; Reed and Robbins, 2008) have concluded that texting and driving is a greater safety threat than dialing a cell phone (Ranney et al., 2011), driving drunk (Elvik, 2012), smoking cannabis (Asbridge et al., 2012; Elvik, 2012), or talking on a cell phone (Caird et al., 2008; McEvoy et al., 2005; Redelmeier and Tibshirani, 1997).

4.1. Implications for countermeasures

To prevent an increasing number of traffic related deaths and injuries, typing and reading text messages while driving should be targeted by legislation and enforcement, as well as more informal methods that include changing social norms, parent modeling, and modifications to driving training and education. Clearly, a multi-method prevention approach to this complex problem will be required. The U.S. Governors' Highway Safety Administration (GHSA, 2013b) provides a comprehensive list of legislation, social media, education, partnership and public policy sources that are focused on cell phone and texting distractions. For example, a number of government bodies, institutions and corporations have implemented texting and driving bans. Within the U.S., 41 states, the District of Columbia, Puerto Rico, Guam and the Virgin Islands have imposed restrictions on texting and driving (GHSA, 2013a), as have Canadian provinces (CCMTA, 2013) and European countries (Jamson, 2013). Extrapolating from evidence based on the impacts of cell phone laws, texting laws may produce partial compliance based on education and the challenges associated with enforcement (GHSA, 2013b; McCartt et al., 2010). However, the overall effectiveness of texting laws remains to be determined (IIHS, 2010; Jacobson and Gostin, 2010). For example, small increases in crashes in certain crash types after universal texting restriction in Michigan were observed (Ehsani et al., 2014). Drivers may position their phones deeper into the vehicle, such as in their laps, to avoid being seen by the police. Glances to a phone in the driver's lap would be longer and thus increase the probability of a crash. The certainty of this behavioral explanation requires additional observational and epidemiological evidence.

Parents of young drivers have an important role in establishing safe behaviors. Modeling the behavior of *not* texting while driving is important, as is setting limits while driving such as when the use of cell phones is appropriate (e.g., in an emergency, while safely stopped), monitoring resulting behaviors and reinforcing safety-related behaviors (Klauer et al., 2014; Simons-Morton et al., 2006).

Doctors and health care professionals also play an important role in acting on the evidence that has now accumulated on texting and driving through interaction with their patients, public and peers (Jones, 2014). Adding the question "Do you text and drive?" to discussions with young patients at the general practitioner's office may help to modify some drivers' behavior (Ship, 2010). Forty-seven percent of U.S. pediatricians said that they "almost always" or "often" counsel adolescent drivers about the safety of using cell phones while driving (Weiss et al., 2012), but this rate could be higher and include warnings about texting. Emergency room physicians may also have the texting and driving conversation with patients after waiting while patients finish a text or call (Kahn, 2011), but before they need a chest tube or a pelvic binder after a crash (Chakravarthy and Lotfipour, 2012). Personal safety messages from authority figures about not texting and driving, especially when communicated in close proximity to a near miss, may also change some drivers' future behaviours (Phillips et al., 2011).

4.2. Limitations

The current meta-analysis contributes to the research literature and has clear population health policy implications, but it is not without its limitations. First, the number of studies for each dependent variable and task type is relatively small, which affects the certainty and stability of some of our effect size estimates. However, given the thoroughness of the search of published and 'grey' literature, the effect size estimates presented here are indicative of the state of research within the domain at this time.

Second, a number of dependent variable effect size credibility intervals indicate the presence of heterogeneity or moderator variables. Individual differences represent a set of potential grouping variables that may provide a more complete account of heterogeneity. For example, drivers engage in distracting activities even when they know that it is unsafe to do so (Atchley et al., 2011; Goodwin et al., 2012; O'Brien et al., 2010; Nemme and White, 2010); social expectations and individualized responses to these demands—especially among young driver peer networks—may increase or decrease the likelihood that they will text and drive. Similarly, gender differences between men and women may account for some lateral control differences (Reed and Robbins, 2008), texting frequency (O'Brien et al., 2010) and decisions to use electronic devices while driving (Foss and Goodwin, 2014; Goodwin et al., 2012). Older and younger drivers differ in both texting frequency while driving and texting skill (Owens et al., 2011; Stavrinos et al., 2013). The inclusion of a more diverse sample based on older ages is likely to establish that our meta-analytic estimates of driving impairments are somewhat optimistic. Future research should examine individual differences in texting and driving, as these variables could not currently be coded.

Third, drivers may engage in a variety of safety strategies—such as texting while stopped at traffic lights, pulling over to the side of the road and having passengers text for them—that are not sufficiently measured within simulation or test track experimental protocols (Caird and Horrey, 2011). Thus, the true effects of text messaging on driving may be different than those reported in this meta-analysis because of the inherent limitations of experimental settings. Similarly, if drivers know the risk of texting and driving and exhibit their best performance in experimental or naturalistic studies, driving behavior in their own vehicles may be worse than when being measured by researchers (Evans, 2004). Observational studies of young drivers in their own vehicles indicate that they have a higher crash risk while engaged in texting and driving (Klauer et al., 2014). The implication of these limitations is that the effect sizes reported in this meta-analysis are likely conservative estimates.

4.3. The future of driver distraction

The evolution of 'smart' phone hardware, operating systems and application software will continue to have unintended consequences when these phones are used while driving. The entertainment and information choices available to drivers will continue to expand for the foreseeable future through smart phones and integrated functions such as "social" and "connected" vehicle designs. For example, email, tweeting, photo and video sharing, location-based services, maps, games and an endless variety of apps encourage a multitude of additional distracting activities (GHSA, 2013b). Frequent and prolonged glances away from the roadway as a result of these interactions will also compromise driving safety and will add to the disease burden of road traffic crashes throughout the world—a disease burden that ranked 8th overall in the global years of life lost (YLL) rankings in 2010 (Lozano et al., 2012). Of particular concern, the premature mortality of young drivers who crash as a result of distractions has a greater effect on YLL than most other diseases.

5. Conclusion

Typing text messages reduces drivers' capability to adequately direct attention to the roadway, to respond to important traffic events, and to control a vehicle within a lane and with respect to other vehicles. Typing and reading text messages compromises the safety of the driver, passengers and other road users—especially in young drivers who often use these technologies while driving. Legislation and enforcement, changing social norms, improved driving training and education, and changes to automotive design will be required to prevent additional deaths and injuries from texting and driving.

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