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Distracted Walking, Bicycling, and Driving: Systematic Review and Meta-Analysis of Mobile Technology and Youth Crash Risk

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Abstract

This paper examined the impact of mobile technology on young pedestrians, bicyclists, and drivers. A systematic search yielded 41 papers meeting inclusion criteria: peer-reviewed, published before 2/1/16, behavioral outcome related to pedestrian, bicycling, or driving in the presence of mobile technology use, youth sample. Eleven studies were meta-analyzed to evaluate increased risk for crash/near-crash while distracted. Risk of bias and quality of research were assessed. Across methodologies, developmental stages, and type of distracting task, mobile technology use impairs youth safety on the road. Quality of evidence was low (pedestrian) to moderate (driving). Findings are discussed from the perspective of cognitive and visual distractions. Policy and behavioral efforts should continue to reduce mobile technology use in transportation settings.

Keywords

mobile phone technology; distraction; driving; pedestrian; bicycling; child; adolescent; behavior; transportation

Youth mobile technology use is ubiquitous, and the ways children use mobile technology are evolving. In the United States (US), 68% of children ages 12–13 and 83% of children ages 14–17 owned a cell phone in 2013. That same year, 37% of children ages 12–17 owned a smartphone with internet access (Madden, Lenhart, Duggan, Cortesi, & Gasser, 2013). Mobile technology offers many advantages, including convenience, entertainment, and education, but it also creates risk, including when technology is used in contexts such as roadways.

Transportation-related injuries account for the largest portion of fatalities to US children ages 5–24 (Centers for Disease Control and Prevention [CDC], 2016). Inattention evoked by secondary task engagement in road environments, or "distracted walking" and "distracted driving," is a significant contributor to unintentional road injuries (National Highway Traffic Safety Administration [NHTSA], 2013a), and is a primary explanation for the increasing

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rates of US pedestrian injuries (Retting & Rothenberg, 2015). Although distraction impacts safety across the lifespan, youth are overrepresented in such incidents in transportation contexts (NHTSA, 2013a).

Mobile technology use impacts youth crash risk in two ways. First, distracting technology draws resources of four domains: visual (eyes off the road), cognitive (mind off the road), manual (hands off the wheel), and aural (listening off the road, especially relevant when walking or bicycling) (Figure 1). Mobile technology tasks may tap one domain or several. Second, the frequency with which individuals multitask (exposure opportunity) is associated with safety. Thus, a low demand task can be a significant safety problem if engaged in frequently. Little research addresses manual or aural distraction in traffic, so this systematic review and meta-analysis focuses on how mobile technology use places demands on visual and cognitive processes that may impact youth crash risk.

There are similarities in negotiating roadways across modes of transportation. Walking, bicycling and driving require visual/perceptual skills to evaluate dynamic (constantly changing) environments with substantial visual stimuli. As the environment is perceived, information is cognitively processed and efficient decision-making about environment engagement is required for safety. Anticipatory behavior and executive function skills are essential. Young and developmentally immature pedestrians/bicyclists/drivers make more errors than older, more experienced road users (Demetre et al., 1992; Mayhew, Simpson, Pak, 2003; Plumert & Kearney, 2014), even in the absence of distracting secondary tasks.

There also are key differences across modes of transportation. Manual processes are more prominent for pedestrians and bicyclists. Similarly, aural stimuli are hypothesized to be utilized in pedestrian and bicycling environments (Schwebel, 2013), but loud music in a car plays a minor role in driver safety (Ünal, Steg, & Epstude, 2012). Visual and cognitive processes, and the role distraction plays to interfere in those processes, may be more consistent across domains of road engagement.

Interplay of Visual and Cognitive Processes in the Road Environment

Attentional theory (Posner & Petersen, 1990) offers a conceptual framework for how distraction may impact youth safety. Negotiating street environments requires ability to sustain visual and cognitive attention to multiple stimuli in a dynamic environment. Attentional focus must remain on cues most diagnostic for the task (Romer, Lee, McDonald, & Winston, 2014), and unrelated distraction can impact these processes substantially (Barton, 2006). Across transportation modes, visual attention skills are associated with safety (pedestrians: Barton, 2006; bicyclists: Vansteenkiste, Cardon, & Lenoir, 2015; drivers: Romer et al., 2014), and scholars consistently discuss development of visual capacity as relevant to road safety (Keating, 2007; Mayhew et al., 2003).

Attentional allocation between primary (negotiating traffic) and secondary (mobile technology) tasks, dual-task interference, limits cognitive resources for both tasks. Multiple resource theory suggests youth dividing attention between mobile technology and traffic negotiation suffer from diminished cognitive processing ability (Wickens, 2008). Dual-task performance is affected more dramatically when performing similar tasks (Wickens, 2008), and both mobile technology use and negotiating traffic are largely visual and cognitive activities.

Other sources of distraction interference in traffic environments include complexity of the roadway, salience of events, effort demand required to multitask, and value of the information presented (Wickens & Horrey, 2008). Individuals are active controllers of their own attention at multiple levels (e.g., visual, cognitive, manual, strategic) and distraction-related mishaps may result from breakdown of control at any level. Distraction-related crashes may emerge from dual-task interference or from inability to control potentially distracting interactions (Lee, Regan, & Young, 2008).

The Current Review

Our systematic description of the distraction and youth transportation safety literature extends previous work – a non-systematic review examining mobile technology and walking (Mwakalonge, Siuhi, & White, 2015), a systematic review of driving safety across the lifespan (Klauer et al., 2015), and three meta-analyses on distracted driving (Caird, Johnston, Willness, Asbridge, & Steel, 2014; Caird, Willness, Steel, & Scialfa, 2008; Simmons, Hicks, & Caird, 2016) – in three ways. First, we frame our review in the context of visual and cognitive processes and their impact on applied safety outcomes, emphasizing the theoretical mechanisms behind road risks for distracted youth (Figure 1). Second, we frame our review in terms of development, considering individuals through age 25 since brain maturation in regions related to multitasking and attention allocation occurs through emerging adulthood (Giedd, 2008). Third, we consider the impact of distraction across three modes of transportation.

Method

Systematic review

We conducted a systematic literature search in four databases (MEDLINE (PubMed), PsycINFO, Scopus, SafetyLit) - using the following search terms: (distract* OR inatten* OR mobile OR “cell phone” OR cellphone OR text* OR “smart phone” OR “handheld device” OR “electronic device”) AND (pedestrian OR driv* OR transport* OR vehicle OR walk* OR bicycl* OR “pedal cycl* OR “pedalcycl*”) AND (child* OR adolescen* OR teen* OR youth OR “emerging adults” OR pediatric OR paediatric). Searches were filtered to exclude books/editorials/comments, include only studies with humans, and include original scholarly work. The following inclusion criteria were used: (1) pedestrian, bicycling, or driving; (2) child or adolescent participants (mean age ≤21 years; range ≤25 years maximum to ensure a focus on childhood to emerging adulthood rather than adulthood); (3) results specific to presence of and/or interaction with mobile technology use; (4) behavioral outcome linked to mobile technology use (i.e., not a self-report outcome); (5) peer-reviewed; (6) behavioral research and not population-based epidemiology; (7) published prior to 2/1/16 in any language.

Manuscript selection occurred in two steps (Figure 2). First, the initial 2218 search results, after removing duplicates, were independently evaluated for relevance based on titles/abstracts, or full text when abstracts were absent/vague, by two authors (inter-rater reliability $\kappa > .9$). Differences were resolved by a third author. Second, for the 138 retained manuscripts, full texts were reviewed for inclusion criteria; 41 were retained. The following data were extracted: bibliographic information, country of data collection, transportation mode, sample demographics, sample sizes allocated to groups and studied at each time of assessment, methodological approach, behavioral outcome measures, and results (Table S1).

Meta-analysis

Data Extraction and Processing—Among the 41 studies in the qualitative synthesis (5 on pedestrians, 1 bicycling, and 35 drivings), 31 were excluded from the meta-analysis (Figure 2). Data extraction was conducted on the 10 included articles (11 studies) using a structured protocol. Two independent senior researchers reviewed the data extraction and resolved disagreements by discussion. Data were entered into Comprehensive Meta-Analysis 3.0 (Biostat, Englewood, NJ) for analysis. The meta-analysis included studies examining the effect of mobile technology use on the applied safety outcome of near-crash/crash (simulated or real-world), because this outcome is a direct measure of pediatric transportation safety. A single study on bicycling met inclusion criteria, but was omitted from the meta-analysis.

Assessment of Risk of Bias—Bias at the meta-analysis level was minimized by including all possible studies using a systematic, comprehensive literature search. Biases at the individual study level were evaluated by two researchers according to Cochrane guidelines. The bias domains assessed were random sequence generation (selection bias), allocation concealment (selection bias), blinding of outcome assessment (detection bias), incomplete outcome data (attrition bias), and selective reporting (reporting bias). Discrepancies were resolved through discussion.

Quality of Research Assessment—Based on GRADE guidelines (Guyatt et al., 2011), we assessed quality of evidence with one researcher conducting ratings and a second reviewing ratings. Disagreements were resolved through discussion. Ratings were downgraded based on poor methodological quality, potential biased results, indirect evidence of results, imprecision of results, risk of publication bias, and heterogeneity of results. Upgrading criteria included large magnitude of effect sizes.

Data Analysis Plan—Descriptive analyses were computed for each study in the qualitative analysis. Meta-analysis was conducted in two steps. First, tests of the effect of mobile technology-related distraction on pediatric safety were conducted for crash/near-crash outcomes. We computed and aggregated effect sizes using Hedges' g, a less-biased version of Cohen's d that can be interpreted using the following criteria: small effect (0.20–0.49), medium effect (0.50–0.79), and large effect (> 0.80). To minimize bias in estimating confidence intervals at the study level, an overall effect size was computed respectively for each mode of transportation. If effect sizes of the included studies were heterogeneous (Q significant or $I^2 > 50\%$), a fixed-effect model was used to interpret the aggregate effect size.

If the effect sizes were homogeneous (Q significant and $I^2 < 50\%$), a random-effect model was used. Next, effect sizes for pedestrian and driving were computed separately for talking (cognitive distraction) versus interacting with a phone (e.g., when a youth presses buttons on the phone, such as while dialing, answering, texting, or using the internet; both cognitive and visual distraction).

Results

Descriptive Characteristics: Studies in Qualitative Review

Forty-one articles met qualitative study inclusion criteria. Summarized qualitative results are below.

Pedestrians and Distraction—The 5 distracted walking studies utilized either experimental designs with virtual reality pedestrian environments (Byington & Schwebel, 2013; Chaddock, Neider, Lutz, Hillman, & Kramer, 2012; Parr, Hass, & Tillman, 2014; Stavrinos, Byington, & Schwebel, 2009) or observational strategies (Thompson, Rivara, Ayyagari, & Ebel, 2013). Developmental differences were minimal: Mobile technology use impaired pedestrians' visual attention to traffic in children ages 10–11 (Stavrinos et al., 2009) as well as emerging adults (Byington & Schwebel, 2013; Thompson et al., 2013).

When distracted by visually demanding tasks (e.g., texting), pedestrians waited longer, missed more opportunities to cross safely (Byington & Schwebel, 2013), and crossed more slowly (Parr et al., 2014). Step width, toe clearance, step length and cadence also diminished while texting (Parr et al., 2014). In observational field research, texting pedestrians were more likely to cross unsafely (Thompson et al., 2013). When distracted cognitively but not visually demanding tasks (e.g., phone call), pedestrians waited significantly longer to cross, missed more opportunities to cross safely (Stavrinos et al., 2009), and crossed more slowly (Thompson et al., 2013).

Bicycling and Distraction—One paper on distracted bicycling met inclusion criteria (Kircher et al., 2015). Using experimental strategies, it reported that bicyclists ages 16–25 used conscious strategies, including stopping or adapting their speed, to accommodate visually demanding tasks (e.g., texting/interacting with phones). An additional study published after our systematic review inclusion date was derived from the same dataset and showed that cyclists use visual compensatory strategies when interacting with mobile phones while cycling (Ahlstrom, Kircher, Thorslund, & Adell, 2016).

Among adults, research generally suggests distracted bicyclists use compensatory strategies (e.g., reduced speed) to handle tasks perceived as difficult (Adell, Nilsson, & Kircher, 2014), especially when visually distracted (de Waard, Schepers, Ormel, & Brookhuis, 2010; de Waard, Lewis-Evans, Jelijs, Tucha, & Brookhuis, 2014). Distracted adult bicyclists also exhibit delayed response times (de Waard, Edlinger, & Brookhuis, 2011) and less head movement (de Waard, Westerhuis, & Lewis-Evans, 2015), but the adult literature is mixed regarding whether distracted bicyclists have increased crash risk (de Waard et al., 2010; Terzano, 2013).

Driving and Distraction—Thirty-five manuscripts on distracted driving met inclusion criteria. Various methodological approaches were used, including experimental driving simulator studies, instrumented vehicles on predetermined routes, and observational/naturalistic studies involving in-vehicle recording devices. Novice and experienced drivers were both impacted by mobile technology use (Stavrinos et al., 2013), though interacting with a phone resulted in significantly more lane deviations by teen drivers compared to older, more experienced drivers (Greenberg et al., 2003; Wikman et al., 1998), as did phone dialing (Reed-Jones et al., 2008).

Across studies, visually demanding mobile technology tasks (texting) diverted drivers' attention from the forward roadway (Farmer, Klauer, McClafferty, & Guo, 2015a; Foss & Goodwin, 2014; Greenberg et al., 2003; Hosking, Young, & Regan, 2009; Kingery et al., 2015; Neale, Dingus, Klauer, Sudweeks, & Goodman, 2005; Wikman, Nieminen, & Summala, 1998). The effect of texting on response time produced mixed results, with several studies suggesting it significantly slowed driver response (Drews et al., 2009; He et al., 2015; Sawyer et al., 2014; Simons-Morton et al., 2015) and one reporting no effect (Hosking et al., 2009). Sending text messages led to more lane position variability and more lane excursions (Hosking et al., 2009), behaviors which were mediated by extended eye glances off the road (Kingery et al., 2015).

Overall, speed was found to be highly variable, but significantly slower, when engaged in the visually demanding tasks associated with cell phone use while driving (Narad et al., 2013; Stavrinos et al., 2013; Farmer, Klauer, McClafferty, & Guo, 2015b), and speed increased after a call ended (Reimer, Mehler, D'Ambrosio, et al., 2010). Other research found visual phone interactions to be associated with increases in speed over short durations (Farmer et al., 2015b; Reed-Jones et al., 2008). While texting, adolescent drivers' speed has been found to be either faster (Stavrinos et al., 2015) or not impacted (Reimer, Mehler, Coughlin, et al., 2010; Sawyer et al., 2014).

Cognitively, but not visually, demanding tasks of phone conversations did not influence visual attention in naturalistic or simulated settings (Farmer et al., 2015a; Kingery et al., 2015; Kingery et al., 2015). Such cognitively-distracting tasks did, however, cause young drivers to take incorrect exits (Gaspar et al., 2014), miss turns (Kass et al., 2007) and mirror checks (Pereira et al., 2009), pause excessively at stop signs (Reimer, Mehler, Coughlin, et al., 2010; Reimer, Mehler, D'Ambrosio, et al., 2010), and proceed through yellow light indicators (Xiong et al., 2016). Conversing on phones slowed driver response time in three studies (Bellinger et al., 2009; Horberry, Anderson, Regan, Triggs, & Brown, 2006; Strayer & Drews, 2004), but not in a fourth (Narad et al., 2013). Interestingly, a few reports of increased safety during phone conversations are published (e.g., when drivers were engaged in a hand-held phone conversation, they exhibited less variability in lane position [Tractinsky et al., 2013] and fewer lane changes [Stavrinos et al., 2013]). Phone conversations also led to slower (but more variable) speed while driving (Brown, Horberry, Anderson, Regan, & Triggs, 2003; Horberry et al., 2006; Reimer, Mehler, D'Ambrosio, et al., 2010; Tractinsky et al., 2013). These safer behaviors may represent compensatory strategies.

In studies comparing visually distracting tasks to cognitive distracting tasks, texting resulted in more variability in lateral position on the roadway compared to phone conversation (Stavrinos et al., 2013, 2015), no distraction (Drews et al., 2009; He et al., 2015; Narad et al., 2013; Stavrinos et al., 2013) and using Google Glass (He et al., 2015; Sawyer et al., 2014).

Meta-analysis

Figure S1a shows meta-analysis results on the overall effect of mobile technology-related distractions on pediatric pedestrian risk. Significant heterogeneity existed among the effect sizes of the included studies ($Q = 4.45$, $p = .11$, $df = 2$, $I^2 = 55\%$), dictating use of a random-effect model to compute the aggregate effect size and estimate the 95% confidence interval. Results indicated a small-to-medium effect ($g = .42$, $SE = .12$, 95% CI = [.19, .65]), suggesting mobile technology-related distractions exert a significant and small-to-medium detrimental effect on children's risk of near-crash/crash as pedestrians. Similarly, Figure S1b shows results of the meta-analysis on the overall effect of mobile technology-related distractions on adolescent driving near-crash/crash risk. In this case, no significant heterogeneity existed among the effect sizes of the included studies ($Q = 9.40$, $p = .23$, $df = 7$, $I^2 = 26\%$) so a fixed-effect model was used. Results indicate a small-to-medium effect ($g = .33$, $SE = .06$, 95% CI = [.20, .45]), suggesting mobile technology-related distractions exert a significant and small-to-medium detrimental effect on adolescent near-crash/crash risk.

Table S2 summarizes meta-analysis results separated by mode of transportation and type of distraction. For youth pedestrians, interacting with phones exerts a larger threat to safety ($g = .56$, 95% CI = [.34, .78]) than talking on the phone ($g = .30$, 95% CI = [.10, .49]). Similarly, interacting with a phone exerts a larger threat to youth driving safety ($g = .42$, 95% CI = [-.02, .87]) than talking on one ($g = .28$, 95% CI = [.15, .41]).

Risk of bias for the seven controlled studies is listed in Table S3. None showed high risk in any domain. As seen in Table S4, the quality of research evidence for the effect of mobile technology-related distraction on pediatric pedestrian safety was low, primarily due to risks of biased samples and imprecision of results. The quality of research evidence for pediatric driving safety was moderate; it was downgraded primarily because of potentially biased sampling.

Discussion

Our findings indicate mobile technology use impacts both visual and cognitive processes, thus reducing youth safety on the road. This result pervaded mode of transportation (pedestrian, bicycling, driving), youth developmental level, type of task, and study methodology. The strength of results varied somewhat across studies. No studies reported increased safety when distracted, but null results did emerge in several analyses.

Findings revealed parallels among young pedestrians, bicyclists, and drivers. Similarities in tasks involved in the traffic contexts – visual processing of roadway stimuli and cognitive processing of perceived stimuli – may explain overlapping findings. For example, texting had negative consequences in pedestrian and driving contexts for both visual/perceptual (Klauer et al., 2006; Stavrinos et al., 2009) and cognitive (Byington & Schwebel, 2013; Simons-Morton et al., 2015) processing, which led to dangerous outcomes (Byington & Schwebel, 2013; Simons-Morton et al., 2014).

Quantitatively, findings suggested mobile technology-related distractions exerted a significant and small-to-medium detrimental effect on children's risk of near-crash/crash as pedestrians or drivers. The ability to sustain attention, avoid hazards by effectively shifting attention, and avoid distractions impacting safety is critical for safe traffic navigation (Romer et al., 2014). New technologies like Google Glass (Sawyer et al., 2014) and advanced driver support systems may change how attention is allocated, and show promise in mitigating visual distraction during mobile technology use while driving. However, any mobile technology use involves cognitive processes, diverting mental resources away from the primary task. Thus, even relatively low demand tasks such as conversing via hands-free phone involve considerable risk to road users. Our review supports this assertion, as young drivers conversing on phones made errors in multiple studies (Gaspar et al., 2014; Kass et al., 2007; McKnight & McKnight, 1993) despite maintaining visual attention on the road.

Several inconsistencies in the results emerged, especially within driving research. These inconsistencies may be explained by several factors. First, over $\frac{1}{3}$ of included studies had small sample sizes (≤20), likely affecting statistical power. None had sample sizes over 100. Second, there were differences in methodological approaches (e.g., simulator, naturalistic) and differences within the same methodological approach (e.g., simulator fidelity), which may evoke different participant responses. Third, variations in driving demands (e.g., road complexity) could influence the effect of mobile technology use on safety (Tractinsky et al. 2013). Further, various types of traffic hazards may evoke differing responses (Crundall et al., 2012). The field will benefit from methodologies that uncover mediating factors in how distraction by mobile technology influences road safety. As an example, one study suggested increased crash risk while distracted may be mediated by the extent of visual inattention: the longer a driver looked away from the forward roadway, the higher risk of crashing (Simons-Morton et al., 2014).

In some cases, distraction resulted in compensatory behavior among children. For example, Bellinger et al. (2009) found drivers executed more rapid movement to the brake pedal when distracted by phone conversation, and Licence et al. (2015) found pedestrians reduced walking speed when distracted. Compensatory behavior occurs at various levels, ranging from visual/perceptual processing (e.g., driver attempts to text without taking eyes off the road) to cognitive processing (e.g., while distracted, driver, cyclist, or pedestrian slows speed or driver increases headway distance). Future research might consider whether compensatory behavior actually improves safety, how it might influence safety of other road users, and how road users perceive their behavior with respect to how it actually influences them.

While the focus of this review is what goes awry visually and cognitively when children and adolescents use mobile technology in traffic environments, social aspects of distracted behavior cannot be ignored. These aspects include personality and its influence on behavior

(Parr et al., 2016), but most prominently involves youth peer relations. Youth often recognize the dangers of distracted behavior in transportation contexts, yet still engage in it (McDonald & Sommers, 2015); empirical research in other fields (e.g., substance use, sexual risk-taking) offers parallels and perhaps prevention strategies. Second, context likely plays a significant role in youths' decisions to engage in dangerous distracted behavior (LaVoie, Lee, & Parker, 2016). Alteration of context – such as graduated driving laws that prohibit young and inexperienced drivers from ferrying adolescent passengers – may help (Masten, Foss, & Marshall, 2011).

Future Directions

Distraction by mobile devices is a comparatively new phenomenon. The existing literature is youthful and of mixed methodological rigor. Several future directions are suggested. First, the literature has notable gaps. No published work examines how texting may impact pedestrian safety in young children. Similarly, there is little research on distracted child bicycling, especially in mid- to late-childhood. Very few studies have actually assessed pediatric crashrrisk or the effects of manual and aural distractions on youth safety. Second, many studies collapse across age groups and experience levels, complicating efforts to study developmental differences and parse out effects of age vs. experience on safety. Longitudinal studies are needed to examine developmental effects. Third, as technology advances, the ways children interact with technology will evolve. It is imperative that research moves quickly to investigate these effects. For example, how do interactions such as "taking selfies", engaging in augmented reality smartphone games, and posting to social media sites impact traffic safety? Finally, novel approaches to measure how visual and cognitive attention is allocated across multiple tasks are critically needed. The field currently relies on surrogates to assess inattention (e.g., poor vehicle control for cognitive inattention, glances at roadway vs secondary device for visual inattention), but these surrogates are poor proxies. Other domains of distraction should be considered.

Researchers should consider implications for policy and prevention. Despite substantial national attention to policy and enforcement (NHTSA, 2015), adolescent drivers continue to use phones at alarmingly high rates (NHTSA, 2013b). Policy efforts addressing distracted pedestrian or bicycling behavior remain rare. Behavioral interventions outside policy have promise; we are currently evaluating exposure to the risks of distracted pedestrian behavior within a simulated environment as a means to change behavior in the real-world environment (Schwebel, McClure & Porter, 2016).

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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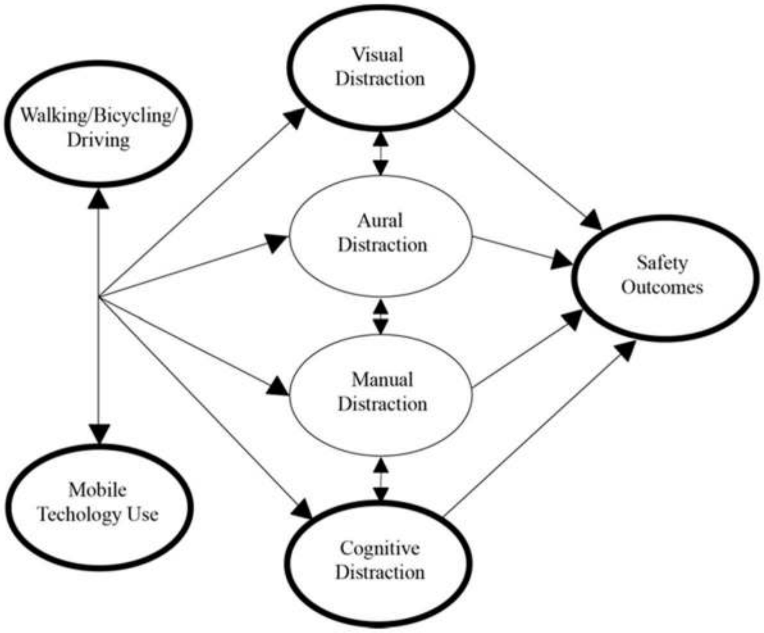

Figure 1.

Conceptual model.

Note. Focus on visual and cognitive distraction due to limited research regarding manual and aural distraction resulting from mobile technology use.

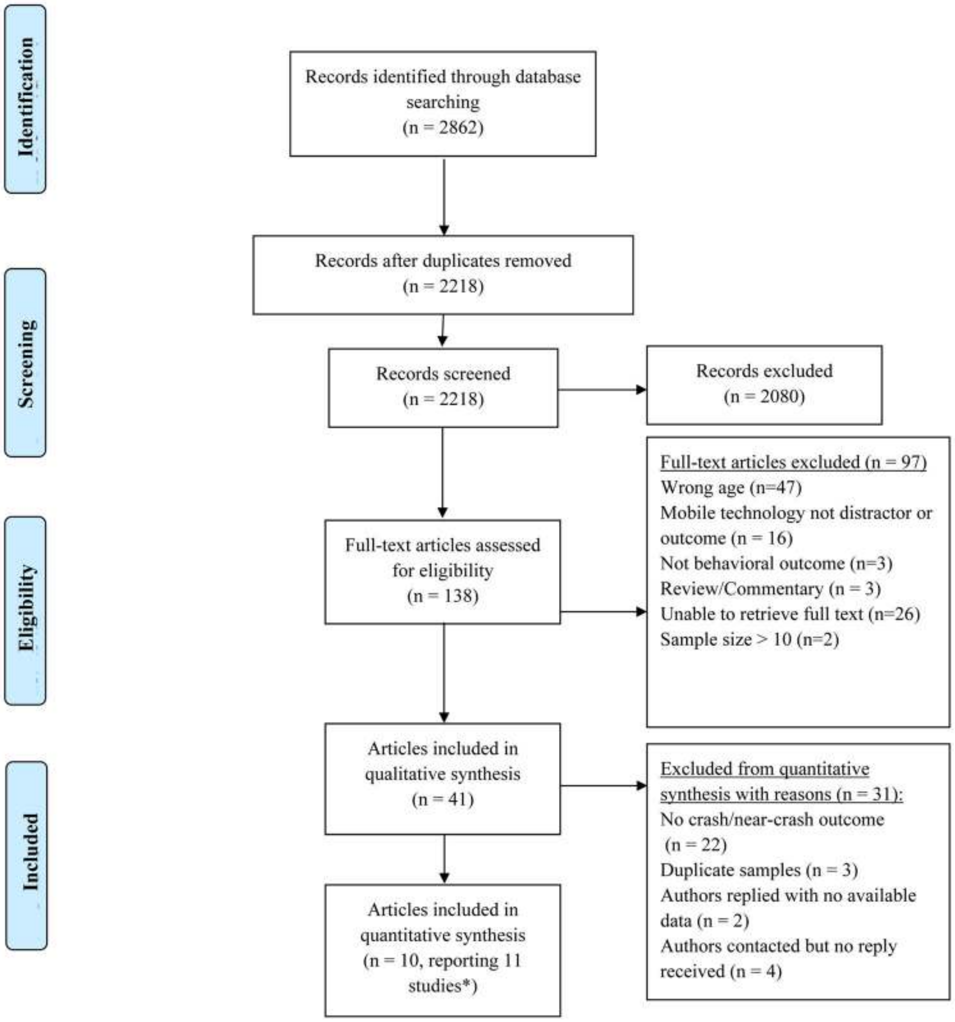

Figure 2.

PRISMA Flow Diagram of Included Studies

Note. *One article, Tractinsky et al. (2013), reported two independent studies.