
Richard Young
Wayne State University

ABSTRACT
There is little agreement in the field of driving safety as to how to define cognitive distraction, much less how to measure it. Without a definition and metric, it is impossible to make scientific and engineering progress on determining the extent to which cognitive distraction causes crashes, and ways to mitigate it if it does. We show here that different studies are inconsistent in their definitions of cognitive distraction. For example, some definitions do not include cellular conversation, while others do. Some definitions confound cognitive distraction with visual distraction, or cognitive distraction with cognitive workload. Other studies define cognitive distraction in terms of a state of the driver, and others in terms of tasks that may distract the driver. It is little wonder that some studies find that cognitive distraction is a negligible factor in causing crashes, while others assert that cognitive distraction causes more crashes than drunk driving. Perhaps the largest problem however is that the definitions typically refer to distraction as a reduction of attention, but never define attention. It is recommended that a new definition of cognitive distraction be created, based on observational data of actual rather than simulated driving. This definition should have associated with it a clear metric for assessing the amount of cognitive distraction for a wide range of tasks, involving different sensory and motor modalities (visual-manual, auditory-vocal, tactile, etc.) A new foundation, grounded in on-road driving data and the experimental study of attention within cognitive neuroscience, may improve the speed at which new and effective countermeasures are developed, crashes are reduced, and driving safety is improved for all.


INTRODUCTION
“Everyone knows what attention is.”
1. William James (1890) [1]
“Keep your mind on the drive instead of the dials with the only radio custom built for your 1939 Buick.”
2. General Motors Corporation (1938) [2]
“Many people automatically presume that it is possible to “still the mind” - not think about anything; have no specific conscious thoughts - for minutes if not hours. But a noted Japanese Zen priest once astounded his novice disciples by stating that the longest he had ever been able to keep his mind blank was one second.”
The current paper is concerned with a critical review of existing definitions, metrics, and models for cognitive distraction, and how prevalent cognitive distraction is before a crash. In a companion paper [4] we attempt a new scientific definition of cognitive distraction while driving based on its relationship to event detection and response. The overall goal is to improve the fundamental understanding of the cognitive processes underlying human-vehicle integration during driving (of which attentional processes are key), to reduce crashes. The questions answered in the current study are:

1. What are the limitations of current “cognitive distraction” definitions during driving?

2. What are the limitations of current metrics and models for “cognitive distraction” effects while driving?

3. Why are there wide-ranging estimates of the prevalence of cognitive distraction preceding vehicle crashes?

1. LIMITATIONS OF CURRENT “COGNITIVE DISTRACTION” DEFINITIONS
Most definitions of cognitive distraction in the driving distraction literature categorize cognitive distraction as one type of driver distraction (e.g., “mind off the drive”). Other types of driver distraction are termed “visual” (e.g., “eyes off the road”) or “manual” (e.g., “hands off the wheel”).
However, beyond the minimal level of agreement that cognitive distraction is one form of driver distraction, there are discrepancies its definition. These discrepancies although often subtle, lead to differences in which secondary tasks while driving are or are not within the scope of cognitive distraction, and what metrics should be used to measure them. These discrepancies in turn have safety consequences, because if a task is not tested for “cognitive distraction” because it is excluded by the definition, then the crash risk potentially associated with that cognitive distraction may be missed (“not defined so did not see”).

A sample of cognitive distraction definitions in the existing driver performance literature is given in Appendix A. (There are also definitions of cognitive distraction in the attention, psychology, and cognitive neuroscience literature, but these are not yet specifically applied to driving.) These definitions can be separated into classes or categories in many different ways. Because of the wide interest in the topic of cell phones and driving, and the frequent association of cell phone conversations (including both hand-held and hands-free conversations) while driving with “cognitive distraction,” we here use the task of cellular conversation to illustrate the differences between the cognitive distraction definitions (even though there are many other ways to categorize the definitions). Thus, the definitions in Appendix A are grouped according to whether they include cellular conversations or not within their scope. (Note that the task of cell phone conversations is not pre-designated as a distraction and then used to judge the definitions; it is simply used to illustrate the underlying assumptions in the different definitions.) The sorting variable of “cellular conversation” is chosen simply for illustrative purposes; other sorting variables give to similar issues. Four of the overall major problems with the definitions in Appendix A are listed in Sections 1.1, 1.2, 1.3, 1.4, most of which apply equally well to the broader category of definitions of “driver distraction” [5,6].

1.1. ATTENTION UNDEFINED

The definitions in Appendix A mostly define “cognitive distraction” in terms of a withdrawal or diversion of attention, but they do not define attention. They rely upon each person's every day or informal understanding of “attention,” as per the quote by the pioneering American psychologist William James [1,7] at the start of this paper that, “Everyone knows what attention is.” The difficulty is that a personal understanding of “attention” may differ from individual to individual. “Introspection” has not been accepted as a valid method of experimental psychology since James' time in the nineteenth century. Relying upon each person's private understanding of the term “attention,” is not suitable grounds for scientific advancement, and may even hinder it.

Relying upon simple dictionary definitions (which use other words instead of scientific data to define things) gives rise to similar problems. It is not clear how metaphorical or figurative definitions of cognitive distraction in terms of other undefined words or concepts will lead to technical advances in understanding cognitive distraction. Regan et al. [6, p. 172] cite the few definitions of “driver inattention” that exist in the driving literature and crash studies (which they note vary in meaning) before defining driver distraction using a dictionary. An interdisciplinary integration between the safety and human factors engineering approaches to driver performance, and the fields of cognitive psychology and cognitive neuroscience, may provide a new foundation to define cognitive distraction and attention - in a way that leads naturally to being able to measure cognitive distraction in driving and thus improves driving safety.

1.2. CONFUSION OF DRIVER STATE WITH DRIVER ACTIVITY

The definitions in Appendix A use the term “cognitive distraction” in incompatible and contradictory meanings. The first meaning refers to a driver activity - things external to the driver's mind, which may trigger the driver's thoughts to go “off the drive.” For example, “Conversation while driving is a cognitive distraction.” The term “cognitive distraction” as used in such definitions refers to the conversation itself, not the state of the driver. This first sense attempts to answer the question, “What activities are a ‘cognitive distraction’ for the driver?”

The second meaning refers to the driver state rather than the activity that distracts the driver. This meaning attempts to define the mental state of the driver when they are cognitively distracted. An example would be, “Cognitive distraction occurs when attention is not focused on the primary driving task.” Definitions in this class refer to the state of the driver, not the activity. This second sense attempts to answer the question, “What happens internally in the driver's mind (or brain) when they are cognitively distracted”?

These are two completely different meanings for the term “cognitive distraction.” This distinction is not trivial - the different meanings lead to practical consequences for deciding which metrics can best assess cognitive distraction and estimate its relative crash risk. Even the design of experiments intended to investigate and assess cognitive distraction will be influenced by which meaning is adopted. The definitions in Appendix A are labeled as “driver activity” or “driver state” to indicate which meaning they appear to be defining, so the reader can better understand the distinction.

1.3. OPERATIONAL DEFINITIONS LEAD TO INCONSISTENCIES

Many studies that claim to be investigating cognitive distraction never explicitly define it. Instead, they just list tasks or behaviors that they record as “cognitive distraction,” in observational terms (see Appendix A, Section 1.4). They do not justify why they included those tasks as cognitive - they just make implicit assumptions that they are, and hope others agree. These are known as “operational” definitions of cognitive distraction. Even though the definitions are not
explicit, operational definitions necessarily contain an “implicit” or unstated definition. The various investigators who wrote the reports or journal articles could not have conducted the research or written up and classified the tasks as they did without an implicit definition. Because “operational definitions” are not within the context of an explicit theory or model, they often subtly change from one section to another in a single report, or from one report to another, even those describing the same data set. If different investigators use different observational data sets and have only operational definitions, it is almost impossible to compare results across studies. This lack of a clear theory or model of cognitive or driver distraction can give rise to inconsistent or even contradictory classifications of tasks and confusing taxonomies, leaving it uncertain as to what the prevalence and relative risk of “cognitive distraction” really is [6].

1.4. “LIMITED CAPACITY” SINGLE BOTTLENECK MODELS MAY BE TOO LIMITED

Almost all the cognitive distraction definitions in Appendix A contain an underlying often-implicit model of a “limited capacity” in a single central “channel” - with an assumption that exceeding some limit leads to a reduction in performance. There are four problems with using the model of a single limited capacity channel as part of the definition for cognitive distraction.

1. Little independent evidence is presented in support of this concept, other that it is useful heuristic for the investigator to explain the data.

2. A single bottleneck model implicitly assumes that less “cognitive distraction” is always better - that optimal driving performance occurs with zero cognitive distraction. Driving itself is a highly multi-tasking activity for the brain, engaging perceptual, cognitive, motor, and many other brain functions. The driver however cannot focus exclusively on driving, because it is difficult or impossible to inhibit extraneous thoughts completely. The brain is always active - there is no “zero state” of brain activation (like there is for alcohol in the blood or eyes-off-road time), and no “zero” state for extraneous thoughts (as per the quote from the Zen master at the beginning of this paper [3] that the mind cannot be blank for more than one second). Indeed, focusing all thought exclusively on driving could lead to monotony and fatigue, reducing driver performance. The Yerkes-Dodson law [8] indicates that there is an optimum level of arousal at which performance peaks - too little or too much arousal gives rise to poor performance. Although driver workload, attention, or distraction are not the same as arousal or brain activity per se, there may be a similar optimum level for cognitive workload - too little cognitive workload may lead to a low arousal state with reduced vigilance. A moderate cognitive workload may improve arousal and performance. With too high a workload, inhibitory processes in the brain play an important role in limiting the “amount” and “extent” of cognitive workload and distraction to a more optimum level for the driver. The way in which brain activity and cognitive workload interact with cognitive distraction may thus be considerably more complex than a simple “limited attention” bottleneck model.

3. A single bottleneck model is not consistent with cognitive neuroscience research of attentional networks in the brain, which indicate that there are three types of attentional networks as per Posner and colleagues [9, 10], (Other investigators say there are fewer or more types of attention, or categorize them in different ways) However, the three network view probably has the most validation in the literature and provides a reasonable framework for quantitative studies of distraction.

4. Performance is multivariate in nature (Angell et al. [11]), with at least two separate underlying dimensions of driver distraction (Young [4], Young and Angell [12]). It is not clear how a single bottleneck model can affect both dimensions.

In sum, the problem of “cognitive distraction” (and driver distraction in general) is more complicated than a simple “limited capacity” bottleneck model. Modern science continues to reveal the function and operation of the underlying brain systems - and they are certainly not simple. Certainly not as simple as a having a single central bottleneck - but it is also not the case that a driver can parallel process and attend to unlimited amounts of information. These complexities and subtleties mean that a scientifically grounded theoretical basis for a definition of cognitive distraction is becoming more important.

2. LIMITATIONS OF CURRENT METRICS AND MODELS FOR COGNITIVE DISTRACTION

2.1. “COGNITIVE TUNNELING”

“Cognitive tunneling” is conjectured to be a top-down attentional phenomenon that affects the ability of the visual system to detect and respond quickly to events in the periphery of the visual field, creating “tunnel vision.” The peripheral field is hypothesized to lose its relative sensitivity to stimuli in comparison to the central field, and so the driver now sees things in the periphery relatively less well than without cognitive tunneling, as if the driver perceived the world through a “tunnel” (Fig. 1) [13].
This phenomenon is considered to occur beyond the fact that peripheral vision has far less acuity than central vision, due to the concentration of cone receptors in the fovea of the eye, within a central visual angle of only a few degrees. In addition, “cognitive tunneling” is conjectured to occur even if the driver remains fixated on the center of the roadway, and so it has unrelated to eye movements.

Some investigators propose “cognitive tunneling” as the underlying model or mechanism for “cognitive distraction.” Therefore, metrics designed to measure peripheral event detection capabilities have been proposed as metrics for cognitive distraction. One of these is the Peripheral Detection Task (PDT), which measures the reaction time and miss rate for a small light stimulus placed in the periphery of the visual field. Another is the Useful-Field-of-View (UFOV©) test where small symbols are placed in the periphery of the visual field and the observer must correctly identify them as rapidly as possible. The investigators who developed these metrics often refer to “cognitive tunneling” as the underlying mechanisms to explain their results. Many other driver distraction studies use the term “cognitive tunneling” or a “narrowing” of the “useful field of view” to explain their cognitive distraction results. A Google Scholar search for a conjunction of the three words “cognitive,” “tunneling,” and “driving” turned up 14,600 citations at the time of writing of the present paper.

There is no question that the UFOV© and the PDT have contributed to improving driver safety. The UFOV© test is correlated retrospectively or prospectively with a driver's crash record for example. Its relation to many of the key major factors that affect driving performance (such as aging) is well established. However, the term “cognitive tunneling” as it has been widely used in driving research does not necessarily arise from a specific loss of sensitivity in the periphery of the visual field, as is often assumed in these studies. Later studies have shown that “cognitive tunneling” is not a specific loss of detectability (measured with miss rates and response times) in peripheral vs. central vision. The original Peripheral Detection Task (PDT) used a peripheral light or lights, and found increased response times (RTs) to such lights with increases in cognitive load. However, later studies have shown increased RT effects with a central light as much as with a peripheral light (Engstrom and Mardh; Victor et al.; Merat et al.), or even with a tactile stimulus (Victor et al.). These later PDT results showing no difference between central and peripheral lights are consistent with Young and Angell, who found that response times were similar for a central and peripheral light administered at different times during the same task, at least for the two major dimensions of driver performance. (There was a difference between central and peripheral response times only in a weak third component, less than 5% of total variation.) These later PDT studies agree that non-localized distractions that lead to a reduction of top-down attentional facilitation (the “spotlight” of attention) affect the entire retina, not just the periphery. Hence, the explanation of so-called “cognitive tunneling” may not really be a specific reduction of sensitivity of the periphery, but rather a reduced sensitivity in the entire visual field.

However, how can a reduction in overall responsiveness to visual stimuli lead to apparent “cognitive tunneling”? Fig. 2 illustrates one explanation. The taller blue curve peaking at “1” represents a (hypothetical) response profile for a driver who is fully alert with orienting attention on the road scene in the forward position (angle 0 in the figure). The exact shape of the blue curve is immaterial; all that is required is a decline in responsiveness away from the center of gaze (such as the reduced responsiveness that is known to occur as a visual stimulus moves away from the fovea or fixation point).
green line, assume the drivers can respond to the stimulus, otherwise not. The “useful field of view” would then be the distance between the two points where the blue curve intersects the green line to the left and right of the center of gaze. The field size is here measured at 3.32 angular units (see distance marker at top of Fig. 2).

Now assume that the “spotlight” of orienting attention is diverted away from the fixation point by a stimulus in some region of the visual field that is more than three units away from the fixation point (location 0 in Fig. 2). Then as shown by Posner and colleagues [9,10] and others, there is a decline in responsiveness for the now unattended region. The smaller red curve represents an (arbitrary) reduction in responsiveness by 50% compared to the blue curve. The intersection of the smaller red curve with the green threshold line is now only 2.36 angular units (see distance marker at bottom of Fig. 2). The reduction in overall responsiveness has now shrunk the apparent UFOV around the fixed point from 3.32 to 2.26 angular units, or 29%.

Assume that instead of a visual stimulus, some other event occurs which activates a central orienting attentional network. Examples are: an auditory stimulus which is either non-localized, or localized to a region away from the fixation point; or, an auditory-vocal task like counting backwards by 7’s, or verbally repeating the digits one or two back (the “n-back” task) while listening to a sequence of digits. These tasks would be expected to cause a similar reduction in facilitation from a central attentional network or networks, causing a decline in responsiveness to the smaller (red) curve in Fig. 2.

Note that in this example the apparent narrowing of the field of view arises from a lowering of responsiveness over the visual field, not just the periphery. The relative responsiveness of the different regions of the visual field, such as peripheral vs. central regions, does not change - all responses are reduced by 50%. This explanation may be more plausible for the declines in the UFOV© or “cognitive tunneling” than a mechanism that differentially affects the responsiveness of peripheral more than central areas. Note that the overall responsiveness decline need not be a simple decline in luminance or contrast responsiveness [20]. It may instead be a loss of responsiveness for moving or flashing stimuli [21,22]. The same cortical neurons in the visual striate cortex that respond to stationary briefly flashed stimuli (as are used in the UFOV© test or PDT test), also respond to moving stimuli [23,24].

2.2. CHANGE AND INATTENTIONAL BLINDNESS

A recent review [25] defines change blindness as “the surprising failure to detect a substantial visual change.” (This definition is unfortunately subjective because it requires a judgment of surprise.) Inattentional blindness is defined [25] as “a failure to notice an unexpected, but fully-visible item when attention is diverted to other aspects of a display.” Many interesting experiments and demonstrations of change and inattentional blindness have been done in laboratory settings or sometimes even in real-world settings. Unfortunately, none of these experiments has explored these phenomena in actual on-road driving on a closed track or open road. Generalization to real-world driving from these experiments is therefore speculative. Change and attentional “blindness” phenomena may be related to some of the missed events in real-world driving, but the connections have not yet been experimentally made, nor has any relevant data been collected in actual rather than simulated driving. Therefore, it has not yet been experimentally demonstrated that such phenomena occur in a rich natural scene with all the visual cues that cannot be realized on a flat simulator or computer display. This phenomenon may depend on suppression of movement and luminance cues; thus, it may not generalize to real world driving in a substantial manner.

Indeed, the conditions for “change blindness” occur naturally all the time while driving, with or without secondary tasks. Every time a person blinks, their eyes are “off the road” for about a tenth of a second. A change in the visual scene that occurs during the blink technically meets the conditions for “change blindness” of having a blanking interval during which a visual change occurs. Alternatively, every time drivers make a saccade of any kind, they are getting the equivalent of a flashed blanking image equivalent to those used in change blindness paradigms in the laboratory. Thus, normal driving contains the conditions for change blindness every few seconds. Thus, movement and luminance cues must be able to “break through” such change blindness effects in everyday driving.

A simpler explanation for “change blindness” effects on event detection during driver is given by studies on the underlying neural basis for spatio-temporal vision. The vision system is structured in such a way to sample the spatio-temporal derivatives in the visual field [23,24]. If a temporal change happens (such as brake lights on a forward vehicle suddenly turning on), it triggers many “transient” neurons in the visual system which respond to rapid luminance changes. These serve to alert the driver to direct covert attention to that location, usually followed by an eye movement to that location. If the sensory information were blocked because of a blink, saccade, or eye glance off the road, the neural transient arising from the visual stimulus would not occur. When the driver's eyes are back on the road ahead, the brake lights of the forward vehicle might still be on. The driver may then perceive the higher contrast of the illuminated brake lights against the background, or the looming of the forward vehicle as it decelerates. However, the response time of the driver will be slightly slowed because of the loss of the transient information, and the slighter later time of the visual information input.

Inattentional blindness is also not likely in real-world driving. The phenomenon of inattentional blindness can only be demonstrated in a single trial. When the subject becomes aware of the visual change or event, it is not missed again. In
the study of Young and Angell [12], the event stimuli were presented hundreds of times to each driver, through the course of all the tasks they completed. In the experiment of Angell et al. [11] the events were presented only once per trial. Yet the dimensions of driving performance, and the relationship of event detection variables to them, came out about the same in both studies (Young [4]). Hence, “eyes off the road” and “cognitive distraction” (as it relates to event detection) seem to be better explanations for reduced event detection performance during driving [4] than change or inattention blindness.

2.3. GAZE CONCENTRATION

The term gaze concentration refers to the narrowing of eye scan patterns. The eye gaze is directed relatively more frequently to the forward field of view, at the expense of the peripheral field of view. Gaze concentration is measured as an increase of the percentage of eyes-on-road time during for a secondary task. As cautioned by Angell [26, endnote 5] and Recarte and Nunes [27], gaze concentration is a separate and distinct mechanism from cognitive tunneling (Section 2.1). Is gaze concentration a useful metric for cognitive distraction?

Many studies find a concentration of gaze more towards the road center during auditory-verbal tasks as compared to visual-manual tasks: for example, cell phone conversations, or artificial auditory-vocal “cognitively demanding” tasks such as “n-back.” Likewise, Angell et al. [11, p. 8-28]) found long times looking forward at the road particularly occur for auditory-vocal tasks. Cognitive load appeared to lead to a situation “… in which gaze was directed at the forward road, scanning of the mirrors was reduced somewhat (though to a lesser extent than for visual-manual tasks) and some peripheral events were missed (though to a lesser extent than for visual-manual tasks).” It is plausible that with longer looks to the roadway and less scanning of the mirrors, that detection of events reflected in those mirrors will get worse. However, note that this “gaze concentration” effect is not because of a reduction in the useful field of view, reduced sensitivity in the periphery, or “looked but did not see.” It is rather an example of “did not look so did not see.”

Many studies conjecture that gaze concentration is a driving safety hazard. This conjecture is inconsistent however to the well-established finding that relative crash risk is decreased to the extent that the eyes are on the road (Klauer et al. [28,45]). In fact, eyes off the road in the few seconds before a crash was shown by Klauer et al. studies [28,45] as being the single best predictor of relative crash risk in a wide range of driver performance variables examined. If the driver increases gaze concentration during a secondary task, then how could crash risk be increased?

The first argument made by those who say that gaze concentration increases crash risk is that increased gaze concentration is associated with “cognitive distraction,” causing “looked but did not see” errors (this argument is often associated with claims of change or inattention blindness as described in Section 2.2). That is, having eyes on the road may not be sufficient to reduce crash risk - the “mind’s eye” must also be on the road (e.g., “mind on the drive,” as in the 1938 Buick commercial [2] quoted in the Introduction). If so, then when the “mind’s eye” is off the road, then the response to events in the forward roadway must be worse than during normal baseline driving, elevating relative crash risk. One way to test this conjecture is to examine event detection data when the eyes are on the road during auditory-vocal secondary tasks with known increases in gaze concentration. This conjecture would predict that more visual events are missed or response times are slowed during periods of gaze concentration. However, the CAMP-DWM investigators [11] found that auditory-vocal tasks with more gaze concentration had only slight decrements for detection of events on the forward roadway, and these were much smaller than the decrements observed for visual-manual tasks with less gaze concentration. No statistical significance testing for event detection was done in the original CAMP-DWM study [11], but Angell [26, her Fig. 4; 29] re-analysed the CAMP data statistically and showed that there was a statistically significant decrement in response for visual-manual tasks, but not for auditory-vocal tasks.

The second argument is that in some situations, glances off the roadway to critical safety-related locations reduce relative crash risk, so in these situations gaze concentration would increase crash risk. For example, glances to the rear or side view mirrors improve crash risk relative to baseline driving as shown by Klauer et al. [28,45]. That is plausible when you consider that before changing lanes for example, the driver who does not glance in the side mirror (and/or make a head turn over the shoulder) is at increased risk for a crash if a vehicle is in the adjacent lane. However, if a driver is intending to stay in the lane for example, why would not glancing to the side mirrors increase crash risk?

Instead, gaze concentration may indicate that the driver is attempting to drive more safely, not less safely. This hypothesis is known as “compensation.” Young and Schreiner [43] in a large study of 3 million drivers and 2,037 real-world airbag-deployment crashes looked at crash association with hands-free personal conversations made with the OnStar hands-free calling system. The found no increase in relative crash risk, even though it is well established that hands-free cellular conversations increase the response time to a visual event [30], and the brain mechanisms that give rise to an increased visual response time from conversation during driving have been specifically identified in brain imaging studies [31,32]. Young and Schreiner [43] proposed several behavioral mechanisms that could compensate for the increase in visual event response times during cell phone conversations. Observational studies with portable cell phones show that drivers adapt phone conversations to the driving environment, and also adapt their driving behavior to the content of the phone conversations [33,34]. Mazzae et al. [35] found that drivers made fewer calls in heavy traffic than in light traffic, especially when using hands-free phones. Drivers might also tend to engage in calls in less-demanding
driving situations (e.g., when traffic volume is low, when the vehicle is stationary, or when the vehicle is not at an intersection). Such compensatory effects could also include not simultaneously performing other secondary tasks in the vehicle that increase crash risk (e.g., reaching for a moving object, reading, applying make-up, dialing a hand-held device). Such compensatory effects would not be seen in experimental studies because the subjects are expected to perform the tasks in order to measure their workload demand—such studies rarely measure a subject's willingness to perform the task in real-world driving scenarios. It is quite plausible that it is the compensatory behavior of the drivers when they are engaged in conversation using a hands-free embedded device that keeps the crash risk within normal ranges. A similar argument would apply to the increased percentage of gaze time on the forward roadway that occurs during cell phone conversations.

Assume that the driver chooses to undertake an auditory-vocal task. It would be prudent for the person not to change lanes or undertake a difficult driving maneuver, to slow down, and to gaze as much as possible at the forward roadway (including glances at intersections, etc.). Reducing speed compared to baseline increases safety margins to the vehicle ahead, and reduces the demand of concurrent driving (Angell et al. [11, p. 2-18]). Gaze concentration to the forward roadway, reduction in mirror glance time, and slowing were all found in the CAMP-DWM data during auditory-vocal tasks [11]. Indeed, it can be argued that it is prudent in such circumstances not to glance at the mirrors. That is, drivers in this scenario may deliberately shed the mirror task, to concentrate more of their gaze to the forward roadway. They are being more cautious, not less. Thus, it seems contradictory to use gaze concentration as a measure of “cognitive distraction” when it may actually indicate improved “driver focus,” a safety benefit. Even unanticipated situations, such as being overtaken by an 18-wheeler in an adjacent lane, would not increase risk if the driver failed to look in a mirror, but had not intended to change lanes. Relative risk would increase if the driver did change lanes while on the phone without looking at the mirror, and did so more when on the phone than when not on the phone, but this scenario has not been reported in naturalistic studies of cell phone conversations to date, where relative risk is not greater than baseline driving [41].

Why would increased gaze concentration to the forward roadway (with necessary proportional reductions in scanning of the mirrors, if the driver is intending to maintain lane position) reduce crash risk? About 70 percent of crash impact angles are from the direction in the forward scene that can be seen through the windshield (see Fig. 3 based on NHTSA data, redrawn from [36]). Angell et al. [11, p. 8-28] report a finding (not apparently from the CAMP-DWM data) that drivers look 95 percent of the time to their future path, and a Saab finding that “80 percent of the driver's looks are to this region.”

3. COGNITIVE DISTRACTION
PREVALENCE PRECEDING VEHICLE CRASHES

Given the limitations and discrepancies in the definitions of cognitive distraction from the examples in Appendix A, and the limitations of existing metrics for measuring cognitive distraction, it is no surprise that the prevalence of cognitive distraction associated with vehicle crashes varies widely in different real-world crash studies. Appendix B cites studies that indicate that cognitive distraction is a low, medium, or high probable cause of vehicle crashes.

The term “prevalence” as used in driving safety is what is defined as “prevalence rate” in epidemiology, “The total number of all individuals who have an attribute or disease at a particular time (or during a particular period) divided by the population at risk of having the attribute or disease at this point in time or midway through the period” [37, p. 141]. In research examining the role of “inattention” in crashes, for example, the term “prevalence” is the frequency of observing a particular task associated with a vehicle crash, divided by the total number of all the vehicle crashes in the data set. An example of a prevalence statement is, “78 percent of the crashes and 65 percent of the near-crashes had one of these four inattention categories as a contributing factor” [38, p. xli].

Although the crash studies described in Appendix B were in different locations and times, the discrepancies of the prevalence of cognitive distraction, are so large that one must look to fundamental differences in the definitions of cognitive distraction or in their methods of measurement to account for the differences. These issues are further discussed in Appendix B.

Another reason for the differences in the estimated prevalence of cognitive distraction in vehicle crashes may be substantial bias arising from confounding or uncontrolled variables in some crash studies. For example, earlier case-crossover studies of “cognitive distraction” while driving [39,40], which assert that cellular conversations increase the relative risk of crashing by about four times, have a confounding variable of part-time driving in control windows. When the relative risk estimate is adjusted to
control for part-time driving, the relative risk of cellular phones while crashing is close to one [6,41].

3.1. PREVALENCE IS NOT RELATIVE RISK

Another difficulty with many crash studies is that they give only prevalence figures, not relative risks. Prevalence by itself is not a generally useful estimate of driving safety because it does not consider baseline risk. To estimate the relative risk of a secondary task or driver states, for example, there must be a comparison of the prevalence of the task when associated with a crash, to the prevalence of the task when not associated with a crash (the baseline). For example, someone might conduct a study and find that 100% of crashes were preceded in the few seconds before a crash with a driver's heart beating. If prevalence figures were used alone, one could assert (erroneously) that a driver's heart beating is a major causative factor in crashes. However, 100% of the baseline periods in driving also involve a driver's heart beating. Therefore, the relative risk of heart beating while driving is one (100% divided by 100%), meaning the crash risk of a driver's heart beating while driving is no different from that of baseline driving. Similar considerations must be applied to estimates of the relative risk of cognitive distraction.

One example to illustrate this obvious point concerns estimates of the relative risk of cell phone conversations while driving (assumed to be a cognitive distraction in many studies - see Appendix A). Assume that the prevalence of cell phone conversation is about 11% of daylight driving time for combined hands-free and hand-held conversation, as estimated from direct observational studies sponsored by NHTSA [42]. Recent studies [41,41,43,44,45,46,47] indicate that the relative risk of cell phone conversation is close to one. Then it follows that the percentage of all crashes associated with cell phone use during daylight driving time will also be about 11% (all else being held constant). Those 11% of individual crash cases associated with cell phone conversation, however tragic, represent anecdotal evidence, and are not sufficient by themselves to conclude that cell phone conversation elevates relative crash risk. A valid estimate of the relative risk of cell phone conversations while driving can only be made by comparing the prevalence of crashing while engaged in cell conversation, to the presence of crashing when not engaged in cell phone conversation.

One major problem involved in estimating the relative risk for any form of cognitive distraction is that no data on baseline prevalence in real-world driving currently exists. Estimating a valid baseline is necessary to calculate relative crash risk for the reasons given in the previous two paragraphs, and in Appendix B. The baseline problem is further complicated by two additional factors: 1) The potential high prevalence of cognitive distraction in the form of “random thoughts” during normal baseline driving; 2) It is unknown to what extent if any the “cognitive load” of drivers varies in normal baseline driving conditions on the road - there may well be different “amounts” of cognitive “load” in different driving circumstances. A second major problem is that there is yet no fully accepted metric(s) to assess the “cognitive load” of conventional tasks [4]. In addition, it is still not fully known if the amount of “cognitive load” can actually be varied with non-ecological experimental tasks in a valid manner. Because the data are lacking for estimates of baseline prevalence, a valid estimate of the relative crash risk for cognitive distraction cannot be made based on current data. A recent simulator study by He et al. [48] found the frequency of mind-wandering as once every 2.6 secs during simulated driving in no-wind conditions. However, subjects reduced mind-wandering during simulated wind conditions to once every 4 seconds. During mind wandering, there were no changes in lateral vehicle control, headway position or time to contact the lead vehicle, and no crashes. There was increased gaze concentration to the forward roadway, which as shown in Section 2.3 would be expected to reduce crash risk if the driver stayed in the lane. It would be useful to validate these findings with real-world driving.

For such reasons, a new scientific definition and analysis of the underlying attentional mechanisms that may underlie “cognitive distraction” seems warranted. To achieve such a goal, the field of automotive safety may benefit from collaborating in a multidisciplinary manner with the fields of cognitive psychology, psychiatry, and neuroscience. To that end, we have used existing driver performance data to find a “principal component” that is associated with event detection and response, and may be associated with cognitive distraction [4,12]. In future work, we will attempt to relate this component to the three attentional networks identified by Posner and colleagues [9,10]. These attentional networks have recently been applied to driving assessment [49,50,51].

4. SUMMARY

The current definitions of cognitive distraction in the driving literature are widely varying and often contradictory. Some include cell phone conversations in the scope of the definition and others do not. Some use the words “cognitive distraction” in terms of the state of the driver (cognitive distraction means the driver was daydreaming), others use the word to refer something external to the driver's mind or brain (“the task is the cognitive distraction”). In addition, metrics such as the useful-field-of-view and the peripheral detection test may have merit for measuring cognitive distraction, but the mechanisms for those effects may have little or nothing to do with an actual decline in the sensitivity of the peripheral vision field with respect to the central visual field. Using “gaze concentration” towards the road center has not been shown to be accompanied by a statistically significant loss in visual object and event recognition in the forward field of view. Gaze concentration may actually improve driver safety rather than reducing it if performed as a countermeasure
during secondary auditory-visual tasks. Because of these and many other uncertainties in the definition of cognitive distraction and the explanation of its underlying mechanisms, the prevalence of “cognitive distraction” preceding a crash varies widely among real-world studies of crash causation. A new definition and metric for cognitive distraction seems warranted.

5. CONCLUSIONS

1. Existing definitions of cognitive distraction while driving have many inconsistencies and gaps.

2. The predominant existing models and metrics for explaining or measuring cognitive distraction have limitations.

3. The prevalence of cognitive distraction as a crash causation factor is indeterminate, in part because of a lack of a robust definition of cognitive distraction based on scientific principles.

4. A new attempt at a definition of cognitive distraction seems warranted, based on sound scientific principles and well-accepted scientific definitions of attention.

REFERENCES


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DEFINITIONS/ABBREVIATIONS

CAMP-DWM
Crash Avoidance Metrics Partnership Driver Workload

CDS
Crashworthiness Data System

CHMSL
Center High Mount Stop Lamp

HFC
Hands-Free Calling

LBDNS
Looked-But-Did-Not-See

NHTSA
National Highway Traffic Safety Administration

PDT
Peripheral Detection Task

RT
Response Time to Event

UFOW®
Useful Field of View

VTI
Virginia Tech Transportation Institute

CONTACT INFORMATION

Richard A. Young Ph.D.
Research Professor
Department of Psychiatry and Behavioral Neurosciences
Wayne State University School of Medicine
9B-19 University Health Center
4201 St. Antoine, Detroit, Michigan 48201, USA.
ryoun@med.wayne.edu

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Richard A. Young Ph.D.
Research Professor
Department of Psychiatry and Behavioral Neurosciences
Wayne State University School of Medicine
9B-19 University Health Center
4201 St. Antoine, Detroit, Michigan 48201, USA.
ryoun@med.wayne.edu
APPENDIX

APPENDIX A: COGNITIVE DISTRACTION DEFINITIONS AND CELLULAR CONVERSATIONS

To illustrate the differences between many of the definitions of cognitive distraction in the driving performance literature, the definitions are sorted according to four categories: (1) those that exclude cellular conversations, (2) those that include it, (3) those where it cannot be determined whether cellular conversation is included or not, and (4) those that give no definition of cognitive distraction, but still use the term in classifying cellular conversation and other tasks. Another way of sorting the definitions is in terms of whether they refer to a “driver activity” or a “driver state,” or both in some cases. Other definitions are “operational” with only an implicit definition of cognitive distraction. The definitions are classified at the end in parentheses as to which sense is conveyed.

1. DEFINITIONS EXCLUDING CELLULAR CONVERSATIONS

1.1. “A preoccupation with competing thoughts” (Streff et al., 2000) [52, p. 4] (driver state)

1.2. “Thinking about something else, or daydreaming” (Stevens and Minton, 2001) [53] (driver state)

1.3. Stutts et al. (2003) [54] used “operational” definitions only, and were unable to come up with a definition for cognitive distraction. “We were unable to capture any measure of cognitive distraction.” “Talking/listening” on a cell phone was classified as a “distraction variable,” a separate category from cognitive distraction [54, Table IV, p. 24]. (operational)

1.4. “Cognitive distraction” was operationally defined as “lost in thought” and “looked but did not see” in the Post-Crash Interview Form (Dingus, 2006) [38, p. 453]. (operational, driver state)

1.4.1. “Lost in thought” was defined as, “Driver is haphazardly looking around but not at any single distraction.” (operational, driver state)

1.4.2. “Looked but did not see” was defined as, “Driver is looking in the direction of a conflict but does not react in a timely manner. Driver may also exhibit a surprised look at the moment of realization.” [38, Table D-1, p. 854]. (operational, driver state) (Note 1: Naturalistic studies based on analysis of observational data from video cameras may underestimate the number of looked-but-did-not-see cognitive distraction errors, because the video images of the driving scene may not contain sufficient information, or be too difficult to reduce, or to determine if the driver looked at the red light or stop sign or did not.) (Note 2: The categories of “lost in thought” and “looked but did not see” were re-classified as “daydreaming” rather than cognitive distraction in other sections of Dingus et al. (2006) [38, Table D-1 p. 854].

1.4.3. In Appendix B “Data Reduction Variables” (Dingus et al., 2006) [38, p. 498], three additional tasks are classified under “cognitive distraction:” reading, talking/singing without obvious passenger, and dancing to the radio. In Table D-1 and the main tree diagrams for crash causes, however, “reading” and “talking/singing/dancing” categories are now broken out as separate secondary tasks separate from “daydreaming” or “cognitive distraction.” (operational, driver state)

1.4.4. “Talking/Listening” on a cellular device is nowhere classified as a “cognitive distraction” in any naturalistic VTTI study to date, but rather is classified as a separate secondary task in the category of “wireless device” [38, Table D-1, p. 854] (operational, driver state)

1.5. “Driver distraction is the occurrence of any event or object (either inside or outside the vehicle), or driver activity, driving-related or not, physical or mental, that claims part or all of the driver's attentional resources, voluntarily or not, diverting them from what is needed to maintain the safety of the driver or other road users. By “attentional resources,” we mean cognitive, perceptual, or motor resources that are related to human attentional processes.” (Hurts et al., 2011) [55] “This definition implies that all cases of driver inattention (i.e., the driver paying insufficient attention to the driving task) can be classified as examples of driver distraction.” [55] (driver state and driver activity) (Note 1: Driver drowsiness would be classified as driver distraction with this definition because it is a form of inattention to the driving task.) (Note 2: It follows from this definition that you can only label the occurrence of X (an event, object, or driver physical or mental activity) as a distraction if you know that X does not “maintain the safety of the driver or the other road users.”) (Note 3: Cellular conversation has been shown in recent studies not to increase the relative risk above that of baseline driving [41, 43, 44, 45, 46, 47]. Earlier studies that indicated a four times increase in crash risk [39, 40] have been shown to have an uncontrolled confounding factor, leading to a four times positive bias [41, 47]. Therefore, cellular conversation would not be counted as a distraction with this definition.)
2. DEFINITIONS INCLUDING CELLULAR CONVERSATIONS

2.1. “… mental distraction while using a mobile phone, which takes the driver's mind off the road traffic environment. In attempting to concentrate on the phone call the driver is naturally distracted from their primary task, which is to remain in control of a moving vehicle.” Burch (2002) [56] (driver state)

2.2. “Talking on a mobile phone while driving is one of the most well documented forms of cognitive distraction.” “For example, operating a particular device, such as a mobile phone, may involve … cognitive distraction caused by focusing on the topic of conversation rather than monitoring any hazards or changes in the road environment.” (Young et al., 2003) [57, p. 2] (driver state)

2.3. “… glance variables are oppositely loaded with event detection variables for the second driver performance dimension (interpreted as low-workload-but-high-inattentiveness, accounting for 17 percent of variance). That is, some secondary tasks even with driver's eyes mostly on the road have relatively higher missed event rates and longer reaction times. This dimension identifies tasks that make drivers more inattentive to outside events than expected, given that their eyes are on the road.” (Young and Angell, 2003) [12] (driver state, driver activities via task scores)

2.4. The current study was undertaken to establish direct physiological methods for measuring mind-on-the-drive” (Young et al., 2005) [58] (driver state)

2.5. “Workload, in the context of driver distraction, is defined as the competition in driver resources (perceptual, cognitive, physical) between the driving task and a concurrent subsidiary task, occurring over the task's duration, as manifested in degraded lane keeping, longitudinal control, object-and-event detection, or eye glance behavior.” (Angell et al., 2006) [11, p. 1-3] (driver state)

2.6. “Cognitive distraction refers to the mental workload associated with a task and is generally not observable.” Ranney (2008) [59, p. 2] (driver state) (Note: “mental workload” undefined)

2.7. “Consider the difference between a casual phone conversation and a complex conversation of significant importance to the driver. The latter will typically demand more concentration resulting in a higher level of engagement than the former. Factors such as engagement and concentration, while not observable, contribute to the level of cognitive distraction associated with a secondary task.” Ranney (2008) [59, p. 6] (driver state) (Note: “engagement” and “concentration” undefined)

2.8. “Among objective metrics, only PDT Mean Response Time was sensitive to changes in cognitive load associated with the (auditory/vocal) memory-scanning task.” “We concluded that the STISIM/PDT test venue offers sufficient sensitivity for development of a portable test of IVIS distraction potential in production vehicles for visual/manual tasks; improved sensitivity is needed for assess effects of cognitive distraction.” (Ranney, 2009) [60] (driver state)

3. DEFINITIONS AMBIGUOUS ABOUT CELLULAR CONVERSATIONS

3.1. Treat et al. (1979) [61] and Treat (1980) [62] investigated 2,258 real-world crashes through both on-site crash investigations as well as in-depth interviews. This study has been called “perhaps the most in-depth study ever performed in the U.S. on crash causation” (Wang et al., 1996) [63], Treat's study has a broad category of driver errors referred to as “Recognition Errors.” Although the term “cognitive distraction” is not explicitly used by Treat, the description of the four recognition error types in Section 3.1.1 fall into the category of cognitive distraction as defined by many later authors. 3.1.1. Recognition Errors

3.1.1.1. Stop sign. “Driver failed to observe and stop for stop sign … This category applied whenever a conscious driver for any reason failed to notice a stop sign which should have been visible to him, and as a result was involved in an accident because of not stopping for that stop sign.” (driver activity)

3.1.1.2. Inattention (preoccupation). “This category applies whenever a driver is delayed in the recognition of information needed to safely accomplish the driving task, because of having chosen to direct his attention elsewhere for some non-compelling reason.” “Specifically excluded from this category are cases where a circumstance or event compels or tends to induce a shift away from the driving-task matters requiring attention. The category thus denotes an unnecessary wandering of the mind, or a state of being engrossed in thought in matters not of immediate importance to the driving task … Inattention is to be distinguished from the distraction categories, wherein a circumstance compels or tends to induce a shifting of attention away from the driving task, and from the improper and/or inadequate lookout category, wherein the driver encounters situations requiring a distinct visual surveillance activity (in addition to that which is always required) for safe completion of the driving task.” (Treat, 1980) [61, p. 21] (driver state)

3.1.1.3. Inadequate or improper outlook. “This category applies whenever a driver is delayed in his recognition of information needed to safely accomplish the driving task, because he encountered a situation requiring a distinct visual surveillance activity (for safe completion of the driving task), but either did not look or did look, but did so inadequately. Thus, included are both cases where a
driver ‘looks but does not see,’ and the cases where a driver needed to look but did not even attempt to, as, for example, in pulling out to pass without first checking for traffic in the passing lane.” (driver activity)

3.1.1.4. Other. “Delays in recognition for other or unknown reasons. This includes all delays in recognition (as previously defined) which, though known to have occurred, cannot be explained in detail.” (unknown)

(Note 1: “looked but did not see” errors can occur in both “stop sign” and “inadequate or improper outlook” of recognition errors.” “Looked but did not see” errors occurring during a stop sign were so common that Treat and colleagues made it a separate category of recognition error.) (Note 2: Conversation with a passenger is classified by Treat and colleagues as an “internal distraction” and not a recognition error: “Conversation with a passenger which diverts attention from the driving task is considered an internal distraction” (Treat et al., 1980) [62]. An internal distraction is a distraction that happens internal to the vehicle (not internal to the driver. Internal distraction is defined by (Treat et al., 1980) [62] as “some event, activity, object, or person within his vehicle, compelled or tended to induce the driver's shifting of attention away from the driving task.” Unlike recognition errors, internal and external distractions must have such a “trigger event” to compel or induce attention away from the driving task. Presumably, the event, activity, object, or person internal or external to the vehicle might well be associated with an eye movement directed toward the triggering event, and away from the forward roadway. Thus, internal or external distractions as defined by Treat and colleagues would likely be classified in later taxonomies as visual distractions rather than cognitive distractions.) (Note 3: At the time of the Treat study, 2-way wireless devices were not common in vehicles. It is therefore unknown whether Treat and colleagues would have classified crashes during wireless conversations in the same category as passenger conversations, making them an internal distraction, or whether crashes during wireless conversations would have been classified as recognition errors, what many term today a cognitive distraction.)

3.2. Wang et al. (1996) [63] classify “looked but did not see” as separate from distraction, based on the police-reported crashes in the Crashworthiness Data System (CDS). (driver state; not clear if conversation is included).

3.3. “While the sources of distraction may take many forms, it is helpful to examine distraction in terms of four distinct categories; visual distraction (e.g., looking away from the roadway), auditory distraction (e.g., responding to a ringing cell phone), biomechanical distraction (e.g., manually adjusting the radio volume), and cognitive distraction (e.g., being lost in thought).” (Ranney et al., 2000) [64, p. 1] (driver state)

3.4. It has been pointed out by Williamson (2009) [65, p. 394] that, “These first three categories are external distractors, as they are “triggered” from stimuli occurring outside the person, whereas cognitive distraction is internal.” Because the source of distraction from conversation involves external auditory stimuli (the other person’s voice), Ranney et al.’s (2000) [64] definition of cognitive distraction therefore technically excludes cellular or passenger conversations.

3.5. “Cognitive distraction includes any thoughts that absorb the driver's attention to the point where they are unable to navigate through the road network safely and their reaction time is reduced.” (Young et al., 2003) [57, p. 2] (driver state)

3.6. “Other explanations [of driver distraction] refer to cognitive capture, where drivers get locked into a task until it is completed (though some switching between tasks may occur in the process).” (Green, 2004) [66] (driver state)

3.7. “Experts agree that there are three types of distraction: (1) visual-taking your eyes off the road; (2) manual-taking your hands off the wheel; and (3) cognitive-taking your mind off the road” (La Hood, 2009) [67] (driver state)

3.8. “… the term distraction as used in this plan is a specific type of inattention that occurs when drivers divert their attention away from the driving task to focus on another activity instead.” Specifically, “Cognitive distraction: Tasks that are defined as the mental workload associated with a task that involves thinking about something other than the driving task.” (NHTSA, 2010) [68] (driver state) (Note: “attention” and “mental workload” undefined)

3.9. “Distraction is anything that diverts the driver's attention from the primary tasks of navigating the vehicle and responding to critical events. To put it another way, a distraction is anything that takes your eyes off the road (visual distraction), your mind off the road (cognitive distraction), or your hands off the wheel (manual distraction).” (NHTSA, 2011) [69] (driver activity) (Note: “attention,” “mind off the road” undefined; omits auditory distraction)

3.10. “Cognitive distraction: Tasks that are defined as the mental workload associated with a task that involves thinking about something other than the driving task.” (NHTSA, 2010) [68] (driver activity) (Note: confounds cognitive distraction with mental workload)
4. STUDIES WHICH REFER TO COGNITIVE DISTRACTION WITHOUT DEFINING IT

4.1. “Cognitive distraction’ arising from purely cognitive secondary tasks can adversely affect driver performance,’’ citing a study of cellular phone conversation (Salvucci, 2002) [70]. (driver state) (Note: cellular conversation has non-cognitive sensory and motor components - listening and talking - making it unclear why Salvucci refers to cellular conversation as a “purely cognitive” task.)

4.2. Ranney et al. (2007) [71] do not give a definition of cognitive distraction but describe effects of cognitive distraction using a simulated phone conversation. (unknown whether driver state or driver task)
APPENDIX B: PREVALENCE OF COGNITIVE DISTRACTION IN CRASHES

Prevalence alone does not provide a valid estimate of crash risk, as pointed out in Section 3.1. Nonetheless, it is worth noting that there are wide variations in different studies in the estimated prevalence of cognitive distraction in crashes. These studies are grouped into low, medium, and high prevalence categories in Sections B.1, B.2, B.3, and critically examined.

B.1. STUDIES ESTIMATING LOW PREVALENCE

Dingus et al. [38] found in the 100-car “naturalistic” driving study conducted by VTTI that only one crash out of 69 (1.4%) related to cognitive distraction. This case was a “lost in thought” crash with a forward vehicle. There were no crashes with a cause of “looked but did not see” (Dingus et al. [38, Table 5-15]). Other naturalistic driving studies conducted by VTTI have a similarly low involvement of “cognitive distraction” (Olson et al. [44]; Hickman et al. [46]). Note that the VTTI studies all use an “operational” definition of cognitive distraction given in Appendix A (see paragraph 1.4), which did not include cellular conversation.

At the 2009 Driving Distraction Summit in Washington [72], Dingus responded to a question about cognitive distraction, “… our studies, and other studies by the University of Michigan, and the Collision Avoidance Metrics Partnership which was funded by the ITS Joint Program office, generally find in the larger context of driving you can see a performance decrement, but if your eyes are forward, then generally you break through the distraction and avoid a crash - not every time, but almost every time.”

In addition to not including cellular conversations, several other factors may have contributed to the low prevalence of crashes associated with cognitive distraction (particularly “looked-but-did-not-see” errors) in the naturalistic driving studies conducted by VTTI:

1. Dingus et al. [38] state that, “The low frequency counts reflected the difficulty in assessing whether a driver was daydreaming by simply examining the video. Therefore, the true frequency of daydreaming is probably higher than shown …” (Dingus et al. [38, legend to Fig. 7-24].

2. Two crashes were labeled as “cognitive - other” but no further explanation of whether that meant or whether it related to “cognitive distraction” was given in Dingus et al. [38].

3. Cognitive distraction was operationally defined by Dingus et al. (2006) [38] not to include “talking/listening” on a cell phone (see Appendix A, definition 1.4). If cell phone conversation had been included in their definition, then six additional crashes would have been identified as associated with cognitive distraction. (The baseline prevalence would also have gone up by about the same number of crashes, because the relative odds ratio for cell phone conversation is near one.) Cell phone conversations however are obviously not pure “cognitive distractions” because they involve auditory stimulation and involve motor systems required to produce speech, even in a totally hands-free cell phone. There is some justification therefore for VTTI's classifying cell phone use separately from cognitive distraction, with separate subcategories for “talking/listening,” “dialing,” “conversation,” “searching for the phone” tasks, all of which carry different relative risks.

4. The penetration of truly hands-free devices into vehicles at the time the data were collected (two or three years prior to the release of the VTTI 100-car report in 2006) was quite low - limiting the ability of the VTTI 100-car team to observe certain types of sources of potential cognitive loads. If there is not an opportunity to observe a task (such as one with high cognitive load), then no matter how good or poor the definitions and crash taxonomy are, a cognitive distraction effect will not show up in the data.

5. No drivers over 65 years of age were included in the 100-car study. Missed events and longer reaction times (effects associated with driver distraction), as well as more driving errors, occur to a greater extent in older drivers than younger drivers in driving simulator assessments [73,74] (see Caird et al. [75] for a review of four earlier studies showing slower RTs on average for drivers 64-69 years of age compared to younger).

6. It is not clear from the procedures as described in the 100-car study reports [38,45] whether the video recordings with the 100-car study would allow a determination of whether the driver ran a stop sign or red light at an intersection. And if so, whether the gaze directions as measured from the video recordings would be sufficiently accurate to know if the driver had looked at the stop sign or red light or not. If neither of these were known, “looked-but-did-not-see” (LBDNS) errors would not be detected.

7. From the interviews with drivers who had crashes at intersections, it is not clear if the question in the interview form regarding “looked but did not see” errors was used in the video analysis of whether a LBDNS event took place.

For further documentation of why LBDNS errors are not seen in some real-world crash studies see [76,77,78,79].

B.2. STUDIES ESTIMATING MEDIUM PREVALENCE

Comprehensive crash investigation studies find “looked-but-did-not-see” (LBDNS) driver errors (now often used as a term for one form of “cognitive distraction” - see Appendix A) as the second most prevalent definite or probable cause of crashes. Treat et al. [61]
and Treat [62] conducted an in-depth investigation of 2,258 real-world crashes, and found that “looked-but-did-not-see” errors were a definite or probable cause of about 25% of all crashes involving drivers over 65, and about 12% for drivers younger than 65 who crashed [61, p. 12]. Chovan et al. [80] and Fancher et al. [81] also found a high involvement of LBDNS errors in the crashes of older drivers, especially in intersection/crossing path situations. Older driver over-involvement in cognitive distraction errors is not consistent with other studies. Wang et al. [63] reported: “Another surprising finding in the current study was the lack of a significant involvement of [looked-but-did-not-see], and inattention in general, in the crashes of older drivers … Indeed, drivers aged 65 and older were the age group most likely to be coded ‘attentive’ in the current study … The present study … did not find a significant over-involvement of [looked-but-did-not-see] for older drivers as a group.” In general, Wang et al. [63] found that 9.7% of crashes were “involved” with “looked but did not see,” according to NHTSA’s Crashworthiness Data System (CDS), in agreement with Treat et al.’s 12% figure for drivers younger than 65. The National Motor Vehicle Crash Causation Survey [82] found that 11% of 1,376 crashes were the result of “inadequate surveillance” which included looked-but-did-not-see, however no data about age was given.

B.3. STUDIES ESTIMATING HIGH PREVALENCE

Other studies assert that “cognitive distraction” from cellular conversation degrades driver performance more than drunk driving (Strayer et al. [83]). The National Safety Council [84], citing a presentation by Strayer [85] states, “Estimates indicate that drivers using cell phones look but fail to see up to 50 percent of the information in their driving environment.” Other studies, including on-road and brain imaging studies, have not confirmed this high 50% miss rate estimate for events in the forward field of view during cellular conversations or other auditory-vocal tasks while driving [26,29,32,33,86], as long as a driver's eyes are on the road.