Towards an Understanding of Driver Inattention: Taxonomy and Theory

Michael. A. Regan
Transport and Road Safety (TARS) Research, School of Aviation, University of New South Wales, Sydney, Australia

David. L. Strayer
Department of Psychology, University of Utah, Salt Lake City, USA

ABSTRACT – There is little agreement in the scientific literature about what the terms "driver distraction" and "driver inattention" mean, and what the relationship is between them. In 2011, Regan, Hallett and Gordon proposed a taxonomy of driver inattention in which driver distraction is conceptualized as just one of several processes that give rise to driver inattention. Since publication of that paper, two other papers have emerged that bear on the taxonomy. In one, the Regan et al taxonomy was used, for the first time, to classify data from an in-depth crash investigation in Australia. In the other, another taxonomy of driver inattention was proposed and described. In this paper we revisit the original taxonomy proposed by Regan et al. in light of these developments, and make recommendations for how the original taxonomy might be improved to make it more useful as a tool for classifying and coding crash and critical incident data. In addition, we attempt to characterize, theoretically, the processes within each category of the original taxonomy that are assumed to give rise to driver inattention. Recommendations are made for several lines of research: to further validate the original taxonomy; to understand the impact of each category of inattention in the taxonomy on driving performance, crash type and crash risk; and to revise and align with the original taxonomy existing crash and incident investigation protocols, so that they provide more comprehensive, reliable and consistent information regarding the contribution of inattention to crashes of all types.

INTRODUCTION

There is converging evidence that driver distraction and inattention are major contributing factors in crashes (e.g., Beanland, Fitzharris, Young et al. 2013) and safety-critical events (e.g., Klauer, Dingus, Neale et al. 2006). There is, however, little consensus in the scientific literature about what the terms "driver distraction" and "driver inattention" actually mean and how they relate to each other (Regan, Hallet & Gordon, 2011). In the absence of a common definition of these concepts that can be operationalized and used to code crash and incident data, the reliability of the information we have currently on the role of distraction and inattention in crashes is ambiguous (Beanland et al. 2013). Inconsistencies in definition of these concepts also makes comparison of research findings across scientific studies difficult or impossible, as it is unclear whether researchers are in fact measuring the same thing (Lee, Young & Regan, 2009).

CORRESPONDING AUTHOR:
Michael. A. Regan, PhD, Transport and Road Safety (TARS) Research, School of Aviation, University of New South Wales, UNSW Sydney, NSW 2052, Australia; Email: m.regan@unsw.edu.au

Regan, Hallett and Gordon (2011) proposed a taxonomy of driver inattention in which driver distraction is conceptualized as just one of several factors that may give rise to driver inattention. Their taxonomy was data driven; it was derived from the consideration of crash data rather than from attentional theory.

Since publication of that paper, two papers have emerged which are relevant to the taxonomy: an article, also published in *Accident Analysis and Prevention*, which describes the first attempt to use the Regan et al. (2011) taxonomy to classify data from an in-depth crash investigation in Australia (Beanland et al. 2013); and a report on the deliberations of a US/EU expert group convened to develop, from a more theory-driven perspective, a taxonomy of driver inattention (Engström et al., 2013).

The aim of this paper is to revisit the taxonomy proposed by Regan, Hallett & Gordon (2011) in light of these developments, in order to make it more useful and reliable as a tool for coding crash and incident data and for stimulating new research into the etiology and impact of driver distraction and inattention. To this end, we aim in this paper to explore whether the categories of inattention proposed in the original taxonomy are sufficiently differentiated; to consider whether these categories are sufficient for coding crash and incident data; to clarify and elaborate on the categories of inattention proposed, including driver distraction; to begin to characterize theoretically the attentional processes within each category of the taxonomy that give rise to driver inattention; and, finally, to suggest refinements to the taxonomy based on these considerations.

A TAXONOMY OF DRIVER INATTENTION

The relationship between driver distraction and driver inattention is unclear in the literature. One view is that the result of distraction is inattentive driving; but that inattention is not always caused by distraction (e.g., Pettitt, Burnett & Stevens, 2005). This view implies that driver distraction is one of several processes that may give rise to driver inattention. From this perspective, inattention is the outcome of a process rather than a process itself. Another view is that driver inattention is itself a process: and more specifically, preoccupation in internalized thought (e.g., Hoel, Jaffard & Van Elslande, 2010). For some, this very same process is regarded as driver distraction (e.g., Regan et al, 2011).

Regan, Hallett and Gordon (2011) attempted to elucidate the relationship between driver distraction and driver inattention, in the form of a taxonomy of driver inattention. The taxonomy was derived primarily from the analysis of previous attempts to classify data derived from in-depth crash studies - in which crash investigators had differentiated taxonomically (with the benefit of hindsight) between different attentional failures identified as contributing factors in the crashes investigated (e.g., Van Elslande & Fouquet, 2007; Hoel et al. 2010; Wallén Warner, Ljung Aust, Sandin et al. 2008; Treat, 1980).

In this taxonomy, driver inattention is defined by Regan et al. (2011) as "*insufficient or no attention to activities critical for safe driving*" (p. 1775), and several sub-categories define the different mechanisms that may give rise to driver inattention. These sub-categories are described below, following which examples are given of the kinds of attentional "failures" which are captured by these categories.

1) ***Driver Restricted Attention*** *(DRA)*: Defined as "Insufficient or no attention to activities critical for safe driving brought about by something that physically prevents (due to biological factors) the driver from detecting (and hence from attending to) information critical for safe driving." (p. 1775). This category of inattention is brought about by functional limitations of the driver that prevent him/her from attending to activities critical for safe driving. Here, Regan et al. (2011) cite microsleeps, blinks and saccades as examples of functional limitations that can result in a driver missing critical information during moments of change blindness.
Examples: Driver dozes off momentarily, with eyes closed, and hits a pedestrian crossing the street ahead. Driver sneezes, with eyes closed, and fails to see a critical item of information in the driving scene.

2) ***Driver Misprioritised Attention*** *(DMPA)*: Defined as "Insufficient or no attention to activities critical for safe driving brought about by the driver focusing attention on one aspect of driving to the exclusion of another, which is more critical for safe driving." (p. 1775). Here, inattention arises because of the inability of the driver to distribute attention effectively between multiple driving activities which are ongoing, both of which may be equally, or almost equally, critical for safe driving.
Examples: Driver looks over their shoulder while merging onto a freeway and fails to see a lead vehicle rapidly braking. Driver focuses on avoiding animal and fails to see another vehicle.

3) ***Driver Neglected Attention*** *(DNA)*: Defined as: "Insufficient or no attention to activities critical for safe driving brought about by the driver neglecting to attend to activities critical for safe driving" (p. 1775). Here, inattention arises from faulty expectations about the driving situation, resulting in insufficient or no attention to activities critical for safe driving.
Examples: Driver neglects to scan to the left for approaching trains at a railway level crossing, because s/he does not expect trains to be there (because they are rarely or never seen). Driver approaching an intersection with right of way assumes s/he has right of way and neglects to look for conflicting vehicles, resulting in a collision with red light runner.

4) ***Driver Cursory Attention*** *(DCA)*: "Insufficient or no attention to activities critical for safe driving brought about by the driver giving cursory or hurried attention to activities critical for safe driving" (p. 1776).
Examples: Driver does not complete a full head check when merging onto a freeway and collides with a merging car. Driver pulls out to pass without first checking for traffic in the passing

lane. Driver performing familiar driving maneuver allocates insufficient attention in searching for information and fails to detect an oncoming vehicle.

5) ***Driver Diverted Attention*** *(DDA)*: "The diversion of attention away from activities critical for safe driving toward a competing activity, which may result in insufficient or no attention to activities critical for safe driving". (p. 1776). DDA is in this taxonomy equivalent to driver distraction, and can be defined more succinctly as "The diversion of attention away from activities critical for safe driving toward a competing activity, which may result in inattention". Regan et al. (2011) proposed that competing activities can be internal to the mind (e.g., as when daydreaming), internal to the vehicle (e.g., talking on a cell phone) or external to the vehicle (e.g., reading an advertising billboard).

Regan et al. (2011) proposed that Driver Diverted Attention could be further decomposed into two sub-categories:

- ***DDA non-driving-related (DRA-NDR) –*** whereby the driver diverts attention away from activities critical for safe driving toward a competing activity that is non-driving-related. *Examples: Driver looks at cell phone while dialing a friend. Driver thinks about what needs to be done when s/he gets to work. Driver daydreams about a romantic holiday in Paris.*

- ***DDA driving-related (DDA-DR; between driving-related tasks) –*** whereby the driver diverts attention away from activities critical for safe driving toward a competing activity that is driving-related. This is different from Driver Misprioritised Attention. "In the former category, inattention arises from a failure to effectively distribute attention between multiple driving activities which are ongoing, both of which may be equally (or almost equally) critical for safe driving. In the latter, inattention arises from the voluntary or involuntary diversion of attention away from activities critical for safe driving toward a competing, driving-related, activity that is less safety-critical." (p. 1776). *Examples: Driver looks at unexpected flashing fuel warning light in an unfamiliar vehicle. Driver thinks almost continuously about where to find nearest petrol station, because fuel tank is almost empty.*

Within this taxonomic framework, driver conditions (e.g., young, inexperienced, old) and driver states (e.g. bored, sleepy, fatigued, drugged, emotional etc.) are seen as factors that may (a) give rise to one or more of the different processes (DRA, DDA, etc.) that may culminate in inattention, or (b) moderate the impact of these processes when they occur (e.g., a young driver who is affected more than an experienced driver by a source of distraction because s/he has relatively less experience and spare attentional capacity to deal with it.)

THE BEANLAND ET AL. IN-DEPTH CRASH STUDY

There has been only one attempt known to the authors to use the Regan et al (2013) taxonomy to classify road crash data. Beanland et al. (2013) and her colleagues used the taxonomy for coding data from the Australian National Crash In-Depth Study (ANCIS) to ascertain the role of driver distraction and inattention in serious casualty crashes. The data sample contained 856 crashes from 2000-2001 in which at least one party was admitted to hospital with a crash-related injury, and the crashes were coded using the taxonomy. Figure 1 indicates the relative proportion of each of the taxonomic categories for which the driver was at fault (a total of 340 of the 856 crashes).

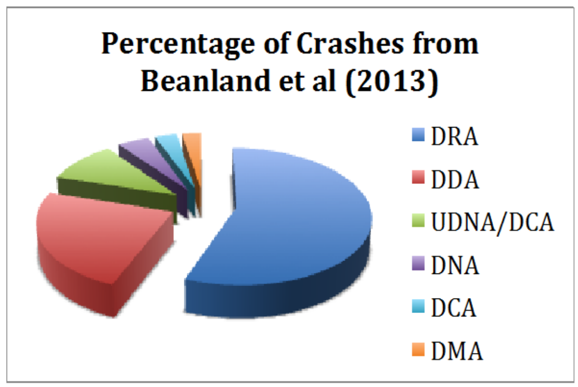

Figure 1. Percentage of Crashes by Inattention Category in Beanland et al (2013) Study

The crashes were coded as follows. A list of possible behaviours was formulated that specified the primary object (e.g., driver, phone, animal) and activity involved (e.g., coughing, dialling, looking at). These behaviours were then independently categorised by two researchers into behaviours within the inattention taxonomy proposed by Regan et al. (2011), with behaviours categorised as "Driver Diverted Attention" further categorised along 5 dimensions: whether it was driving- or non-driving related; it's origin (i.e., internal to driver's mind, in-vehicle, external to vehicle); the sensory modality of the distraction source (visual, auditory, physical, cognitive); and whether the diversion of attention was voluntary or involuntary.

While the relevance of the Beanland et al. (2013) study in the present context is in establishing the validity of the Regan et al. (2011) taxonomy in enabling researchers to code crash data, the findings from the study are of themselves informative. Of the instances for which the driver was at fault and there was sufficient information to code the data reliably, "most showed evidence of driver inattention (57.6%) or possible inattention (5.9%)" (p. 99). In the latter case, "the driver suggested they were probably inattentive, but could not fully remember and there was no corroborating evidence" (p. 103). Beanland et al. (2013) concluded that 70% of distractions were voluntary and hence potentially preventable by the driver and that "The taxonomy itself provides a useful metric for categorizing inattention provided sufficiently detailed data are available, but may not be applicable to all crash datasets." (p. 106).[1]

Beanland et al. (2013) also suggested some ways in which the Regan et al. (2011) taxonomy might be refined to make it more practically useful in classifying and coding crash data:

- It would be beneficial to sub-divide the DRA category in terms of whether the driver has merely restricted attention, or whether the driver had no attention to the driving situation due to a loss of consciousness. As noted by the authors "This distinction has both theoretical relevance to the taxonomy and practical relevance, since the nature and severity of crashes are likely to differ between these subtypes. In addition, for the purposes of developing road safety policy, the circumstances preceding each type of behaviour are likely to differ and as such the various forms of restricted attention may require distinct interventions." (p 104).
- It would be beneficial to include a new category "Undifferentiated DNA or DCA" to address situations in which a driver failed to detect something, but it is not clear whether the driver failed to look (DNA) or looked but failed to properly attend (DCA).
- There was some disagreement between coders about behaviours coded by one coder as "misprioritised attention" and by the other as "driving-related distraction". As noted by Beanland et al. (2013), the critical differentiation between the two categories is whether the driver is attending to a safety-relevant task, which is a context dependant judgement and may ultimately require a case-by-case examination of crashes.

"The findings from the Beanland et al (2013) study suggest that the categories in the Regan et al (2011) taxonomy may not be as clearly defined and differentiated as they might be, and they make recommendations for refining it. While they have highlighted some difficulties, using crash data, in distinguishing operationally between driving-related distraction and driver misprioritised attention in particular, it is not known whether this would be so if the taxonomy were used to classify naturalistic driving data, which provides a generally clearer picture of precipitating factors that bring about safety-critical events. We are unaware of any published NDSs that have used the Regan et al taxonomy for this purpose. Given that Beanland et al (2013) found the categories of the taxonomy

[1] It appears that some of the data collected by Beanland et al. (2013) may have been misclassified. "Sneezing", for example, is classified as Driver Diverted Attention (i.e. distraction). However, the critical mechanism involved in sneezing is automatic eye closure. Hence, this should have been classified as Driver Restricted Attention. "Looked but failed to see" was classified as Driver Cursory Attention. However, the critical mechanism that gives rise to looked but failed to see events is preoccupation in internalized thought, such as when daydreaming, thinking about driving or non-driving activities or engaging in hands-free cell phone conversation. Thus, depending on the nature of the activity at the time, looked but failed to see events should be coded as Driver Diverted Attention (which can be further sub-classified). Finally, "driver confused navigating recently changed road layout" was classified as Driver Misprioritised Attention. This is a difficult case to categorise. Neverethless, it would seem that the critical mechanism involved here is faulty expectation, based on over-familiarity with the original road layout. Hence, in the opinion of the authors, this should should have been classified as driver neglected attention. Beanland et at. (2013) have included within the Driver Restricted Attention category a much wider range of driver states than that envisaged by Regan et al. (2011), including "intoxicated", "pre-crash blackout", "felt ill" and "seizure". To the extent that these driver states functionally limit or prevent the driver in being able to attend to activities critical for safe driving (by, for example, leading to eye closure; or to hearing impairment), then it is appropriate to code them as DRA. If not, they should not be included.

differentiable enough to be able to classify their crash data, with only minor problems, we believe that it premature at this stage to revise or collapse the categories in the taxonomy until the taxonomy is used to code further data from both in-depth crash studies and natural driving studies. This is a necessary part of the systematic process of validating the taxonomy.

THE ENGSTRÖM ET AL. TAXONOMY OF INATTENTION

Engström, Monk, Hanowski et al. (2013) proposed a taxonomy for classifying different forms of inattention in driving that derives primarily from a conceptual framework for attention allocation. The key starting point for their taxonomy is *driver inattention*, which is conceived of in terms of "…*mismatches* between the current resource allocation and that demanded by *activities critical for safe driving*, where "activities critical for safe driving" are defined as those activities required for the control of safety margins. Attentional mismatches may be due to insufficient resource allocation (the activation aspect of attention) or due to allocation of resources to the "wrong" activities (i.e., not matching those activities critical for safe driving; the selective aspect of attention). Furthermore, the presence of inattention is independent of the outcome of the event and, thus, inattention, as defined here, does not have to lead to adverse consequences; nor does it, necessarily, imply driver error." (p. 32).

Thus, for Engström et al (2013), "inattention occurs when the driver's allocation of resources to activities does not match the demands of activities required for the control of safety margins" (p. 25) Engström et al. propose that there are two forms of inattention: insufficient attention and misdirected attention, that relate to the activation and the selective aspects of attention selection, respectively (see Figure 2). Each of these two general types of inattention is associated with a small number of sub-categories, defined by the processes that give rise to them (individually or in combination): Insufficient Attention is decomposed into "Sleep-related Attention Impairment" (which is itself further decomposed into "Drowsy" and "Asleep") and "Insufficient Attention Effort"; Misdirected Attention is decomposed into "Incomplete Selection of Safety-Critical Activities" and "Driver Distraction" (which is itself further decomposed into "Vehicle-External" and "Vehicle-Internal"). (p. 37) Driver Distraction is defined as occurring in situations where "the driver allocates resources to a non-safety critical activity while the resources allocated to activities critical for safe driving do not match the demands of these activities." (p. 35).

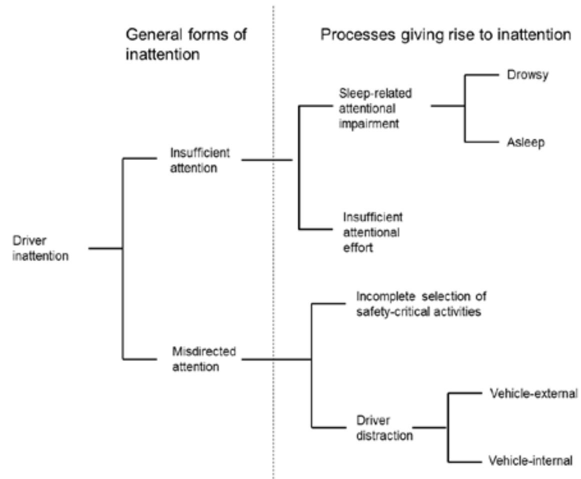

Figure 2. The Engström et al Inattention Taxonomy
(Source: Engström et al, 2013, p. 37; Reproduced with Permission.)

For the most part, the Engström et al. (2013) taxonomy is very similar to that proposed by Regan et al. (2011). However, there are some minor differences. There is no *Driver Restricted Attention* category in their taxonomy; although, as noted, they have a "*Sleep-Related Attention Impairment*" category. Thus, in their taxonomy, there is no provision for inclusion of driver states like intoxication and fatigue that might give rise to, for example, visual occlusion; or for driver behaviors, like sneezing, that momentarily occlude vision.

What Regan et al. (2011) call "Driver Misprioritized Attention" is synonymous with what Engström et al. (2013) call "Incomplete Selection of Safety Critical Events". For Engström et al. this is a subset of the general category "Misdirected Attention". However, in this category Engström et al. (2013) include a case not considered in the Regan et al. (2011) taxonomy: where the driver "…misunderstands the situation and thus allocates resources away from a safety critical activity to another (possibly less) safety critical activity (which, however, is believed by the driver to be the most safety critical)." (p. 34). This case can be accommodated as Driver Misprioritised Attention in the Regan et al taxonomy.

The Engström et al. (2013) taxonomy has no equivalent to the category that Regan et al. (2011) label "Driver Neglected Attention"; although provision is made within the category "Incomplete

Selection of Safety-Critical Activities" for some further cases not considered by Regan et al: e.g., "A driver enters an intersection and allocates visual resources based on his expectation of where potential hazards normally appear. However, this results in a mismatch due to a pedestrian suddenly appearing at an unexpected location and encroaching into the driver's path". e.g., "A US tourist in the UK (used to right-hand traffic) is about to turn left at an intersection but fails to scan to the right for oncoming traffic." (p. 35). Both cases can be coded as Driver Neglected Attention in the Regan et al. (2011) taxonomy.

What Regan et al. (2011) call "Driver Cursory Attention" is synonymous with what Engström et al. (2013) call "Insufficient Attentional Effort". Engström et al. (2013) include in this category two cases not previously considered within the Regan et al. (2011) taxonomy: insufficient attention deriving from fatigue; and "attentional satisficing", in which the alert driver does not allocate as much attentional effort as is required to activities critical for safe driving. What Regan et al. (2011) call Driver Diverted Attention is synonymous with what Engström et al. (2013) label "Driver Distraction". However, in the Engström et al. (2011) taxonomy, no distinction is made between sources of distraction that are non-driving versus driving-related; only between sources of distraction internal versus external to the vehicle.

The Ensgtrom et al (2103) taxonomy is yet to be used as an organizing framework for coding crash and critical incident data. Hence, it is difficult to know whether, operationally, it is any more or less practically useful than the Regan et al. (2011) taxonomy as a tool for distinguishing between different categories of inattention. The specific mechanisms that characterize the different categories of inattention in the Regan et al taxonomy are more transparent than those in the Engström et al taxonomy, and hence the former taxonomy might, in practice, be easier to use. Engström et al point out (p. 38) that most existing taxonomies of inattention are based on "surface-level" categories derived from the analysis of crash data and, thus, lack a theoretical basis in the conceptualization of attention. Hence, one advantage of the Engström et al taxonomy is that it provides a model of what is being classified, which is defined explicitly by a set of theoretical principles. Thus, the proposed sub-categories in the taxonomy can be traced back to those principles and, hence, to the specific attentional problems that define these sub-categories. By conceptualizing inattention as a mismatch between resources allocated and those demanded by activities critical for safe driving (rather than in terms of driver "failures") the Ensgtrom et al taxonomy seeks to avoid conceptual problems related to hindsight bias and the attribution of blame (Engström et al., 2013). Clearly there are advantages in having a taxonomy of inattention that is grounded in attentional theory. In the next section of the paper, we link the Regan et al. (2011) taxonomy with attentional theory.

LINKING DATA TO THEORY

Kahneman (1973; see also Wickens, 1984) developed a conceptual framework in which different activities compete for limited capacity attention and in which the allocation of attention is under flexible control based upon the momentary intentions of the individual (in this case, the driver) and the evaluation of performance on the different activities (e.g., if you begin to drive off the road, then you should allocate more attention to lane maintenance). Arousal may also change the available capacity (e.g., among other things, fatigue can reduce available resources). More recent work from cognitive neuroscience suggests that the allocation of attention to support multitasking is governed by the prefrontal-cortex-mediated executive attentional control network (e.g., Engle 2004; Watson & Strayer, 2010).

Linking the taxomony to attentional theory is more than an academic exercise. If theory suggests that there is no difference in how attention is allocated between two or more taxonomic categories, then this could be a justification for merging them into a single category, even when they may differ in surface level characteristics. That is, theory may help to prune the taxonomy to make it more parsimonious. Linking the taxonomy with theory could also be useful in making predictions regarding teen/novice drivers, older drivers, and clinical populations with attention-related disorders.

In applying attentional resource theory to the driving taxonomy, let X represent the set of driving-related activities. Within the set, some activities are more important to safe driving than others and should therefore have a higher processing priority (e.g., adjusting the windshield wipers would have a processing priority defined by the driving conditions – on a sunny day the priority would be 0). Let Y represent the set of non-driving-related activities that the driver may perform (e.g., placing a call on a cell phone). Activities in both sets X and Y place different demands on limited capacity attention (e.g., driving in dense traffic is more demanding than driving in sparse traffic and listening to the radio places has less cognitive demand than talking on a cell phone).

The "single-task" driving condition is actually a misnomer in that driving is an umbrella term that involves several, functionally independent, activities (i.e., from set X). There is an optimal prioritization of the allocation of attention to these activities (some driving-related activities are more critical to safe driving than others), which evolve over time with the changing task demands. Optimal can be defined based on an allocation policy of $X_a > X_b > X_c > X_d > X_e > X_f$, etc. where each reflect a distinct driving-related activity ranked by safety criticality at time *t*. The ordering of optimal allocation of attention will change over time based on the dynamic changes in the driving environment and the recent behavior of the driver (e.g., if the driver looked in the rear-view mirror at time *t*, then the prioritization of that activity at time *t+1* may be lower because the driver recently performed that activity). If, based on the momentary intentions of the driver, this rank ordering differs and/or some of the activities have a lower prioritization than required for adequate performance, then this represents a case of sub-optimality in the allocation of attention.

There are several potential ways to link behavioral driving data to theory. One possibility would be to use a combination of video/GPS data recorded in the vehicle with eye-tracking measures to associate driving behavior and the allocation of attention with the categories in the taxonomy. The identification of safety-critical activities could be operationalized by a considering a window around time *t* (e.g., 3-5 seconds). Deviations from optimality can be quantified using the Chi Square statistic, with greater Chi Square values representing greater deviations from the optimal allocation of attention at time *t*. This implies that deviations from optimality are on a continuum with greater deviations reflecting a poorer match in the allocation of attention to driving-related activities. Note that it is also possible to have the sum of the optimal priorities exceed the available capacity and performance would also decline.

Figure 3 presents a theoretical optimal allocation of attention (black bars) at time *t.* In the figure, the different activities from set X and Y appear on the ordinate and the abscissa indicates the allocation of attention to these activities (with the total processing priority summing to 100% across the different activities for each of the examples listed below). Note that there is a rank ordering of the processing priority where activities with greater safety criticality have a higher processing priority than less safety critical activities. In this example, the driver has not allocated attention to non-driving activities (i.e., nothing from set Y). Figure 3 also provides an example of the different driver inattention taxonomic categories. An example of DMPA is provided in the red bars, reflecting sub-optimal allocation of attention where $X_a < X_b$ (i.e., more attention is allocated to safety-critical driving-related activity X_b than X_a at time *t*). Lower attention to this safety-critical event will result in impaired performance on that activity at time *t* if performance is in the resource-limited portion of the performance-resource function.

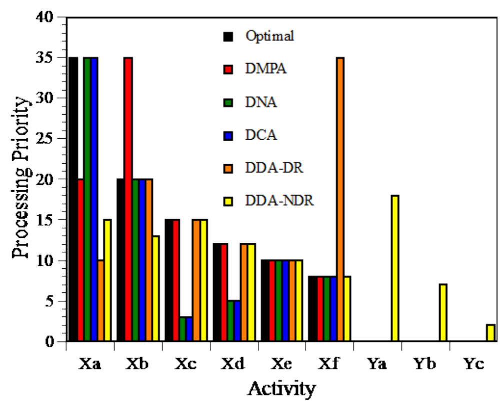

Figure 3: A theoretical optimal allocation of attention at time *t.*

An example of DDA-DR is provided in the orange bars in Figure 3. Here there is inadequate allocation of attention to a safety-critical activity (X_a) and an increase in the allocation of attention to a driving activity that is not safety critical (e.g., changing radio stations). The distinction between DMPA and DDA-DR has to do with the safety-criticality of the activity. There is also a gray area in classifying activities as "critical for safe driving". Is adjusting the radio or cabin temperature driving-related? We propose that the best way to address the issue of safety criticality is to determine if the activity supports the goal of driving (e.g., listening to a radio broadcast of traffic/weather info would be driving-related but listening to a report of the stock market would not be driving-related).

DNA (green bars) and DCA (blue bars) reflect a situation where the processing priority of activities X_c and X_d are sub-optimal. Functionally, DNA and DCA reflect inadequate processing resources to achieve optimal performance; however, they reflect different sources of attentional bias. In the case of DNA, the driver develops expectancies that guide the acquisition of information from the driving environment. These expectancies are contextually sensitive, appropriate in one context but not another (e.g., pedestrians in the US look left before crossing a street, but pedestrians in the UK look right before crossing the street). In the case of DCA, the driver neglects some critical aspects of driving – for example, failing pulling out to pass without first checking for traffic in the passing lane. Note that in both circumstances, drivers do not allocate sufficient attention to activities X_c and X_d.

DDA-NDR (yellow bars in Figure 4) reflects a case of "multitasking" in that the driver is allocating attention to activities from the driving set X and from the non-driving set Y. Moreover, set Y competes for attention in such way that it disrupts the optimal allocation of attention for driving-related activities – that is, attention is diverted from safety-critical driving-related activities. Note that drivers are distracted by a non-driving related activity that competes for limited capacity attention with the activities necessary for safe driving. The competition from secondary tasks depends on the task requirements, so listening to a radio has a lower level of mental workload than talking on a cellphone. Also, it is possible that a driver could "protect" the task of driving (i.e., activities from set X) and only allocate residual attention for Y-activities (i.e., in this case, driving would be unaffected by secondary-task workload, but the secondary-task performance (from set Y) would be compromised.

CONCLUSIONS AND RESEARCH NEEDS

Based on the material reviewed and presented in this paper, several conclusions can be drawn.

First, with one exception, the categories of inattention proposed in the Regan et al. (2011) taxonomy appear to be sufficiently differentiated, at least for classifying crash data derived from in-depth crash investigations: Beanland et al. (2013) suggest that differentiating between Driver Misprioritised Attention and Driver Diverted Attention (i.e., driver distraction) is a context-dependant judgement that may ultimately require a case-by-case examination of crashes. Secondly, at present the inattention categories proposed by Regan et al. (2011) do not appear to be sufficient for classifying crash data: Beanland et al. (2013) suggested that it would be beneficial to include a new category ("Undifferentiated DNA or DCA") to address situations in which a driver failed to detect something, but in which it is unclear whether s/he failed to look (DNA) or looked but failed to sufficiently attend (DCA). Thirdly, the report by Engström et al. (2013) highlights several examples of driver inattention, derived from a review of the attentional literature, that are useful in clarifying and further elaborating the categories of inattention proposed by Regan et al. (2011). As noted, there is very little practical difference between these taxonomies even though the two were derived differently: the former from crash data and the latter from a review of attentional theory. As yet, there are no published data on the utility of the latter taxonomy in classifying inattention-related crashes and safety-critical events. This is an important avenue for future research. Finally, we have attempted to characterize, theoretically, the attentional processes within each category of the Regan et al. (2011) taxonomy that are assumed to give rise to driver inattention. It is our contention that, at least theoretically, there is presently no justification for collapsing the existing categories into a smaller set. However after further studies have been completed using the taxonomy, it might be prudent to prune the taxonomy to suit the specific needs of data analysts.

The preceding discussion suggests a need for several avenues of research. First, further research is needed to further validate the taxonomies proposed by Regan et al. (2011) and by Engström et al (2013), using both in-depth crash data and data from naturalistic driving studies. To be valid, a taxonomy should contain categories of inattention that are mutually exclusive enough to enable researchers to classify crash and incident data, reliably, as belonging to a particular category (or categories). The work of Beanland et al (2013), involving analysis of crash data, suggests ways in which the validity of the Regan et al (2011) taxonomy might be improved. Also, to be valid, a taxonomy should not exclude categories of inattention that might not be observable using extant methods of data collection. The advantage of the naturalistic driving study, for example, is that it yields data that can prove the presence of some forms of inattention, such as distraction, that cannot be easily identified using data from in-depth crash investigations. Secondly, the taxonomic delineation of the different categories of driver inattention creates a springboard for the creation of new research programs to understand the impact of each category of inattention on driving performance, crash type and crash risk. Understanding the types of crashes that result from each category of inattention makes it possible to develop theoretically-based surrogate indicators of inattention and distraction, which could then be applied to large-scale crash data (Beanland et al. 2013). Finally, as also noted by Beanland et al. (2013), existing in-depth crash investigation protocols need to be revised to be in line with the taxonomy of inattention described herein, in order to provide more comprehensive, reliable and consistent information regarding the contribution of inattention to crashes of all types. This information can then be leveraged to develop appropriate interventions and countermeasures.

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