4 A Two-Dimensional Framework for Understanding the Role of Attentional Selection in Driving

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REFLECTION
This chapter was written in reaction to the fragmentation that we perceived in both the basic research on attention and the applied research on driving. Within the basic research, there are a series of micro-theories explaining performance in specific experimental tasks, but there is no overarching theory of attention. Similarly, within the driving research, there are three largely independent traditions: the experimental research, which investigates the effects of various situational variables on driving performance using driving simulators or closed-circuit test courses; the individual differences research, which investigates the attributes of the collision-prone driver, often using psychological tests; and the automation research, which investigates the impact of devices designed to provide drivers with information or take over various
aspects of the driving task. Our framework was designed to unify the basic and applied research, and integrate different streams within the driving literature. The advantage to this common framework is that it helps organize the research, revealing situations where researchers from very different traditions may be doing related research, and conversely, situations where researchers from the same tradition may be producing conflicting results because they are actually investigating different mechanisms of attentional selection. Although it was impossible to list all types of driving research, this chapter was designed to give a sense of the breadth of the field and the diverse ways that attentional selection can affect driving performance.

4.1 INTRODUCTION

Lapses in selective attention, either through inattention or distraction, cause many crashes (e.g., Neale, Dingus, Klauer, Sudweeks, and Goodman, 2005). Although there is consensus that attention has an important role to play in explaining driver performance, the research is fragmented. The goal of this chapter is to provide a framework to unify the literature, drawing together diverging threads to reveal underlying commonalities. In this chapter we summarize fundamental features of the framework, highlighting findings that exemplify key principles. The chapter is divided into three sections: the first introduces the two global dimensions that serve as the basis for the framework; the second outlines the framework, summarizing the four modes of selection; and the third touches on practical implications for crash prevention.

4.2 DIMENSIONS OF ATTENTIONAL SELECTION IN DRIVING

Selective attention is thought to be necessary because there are too many things in the environment to perceive and respond to at once. Specifically, individuals fail to select the appropriate information from the stimulus environment (i.e., they look but fail to see) or fail to select the appropriate response at the appropriate time (i.e., they know what to do but fail to do it). However, at present there is no general theory of selective attention. Instead there are micro-theories for specific tasks, tasks such as orienting, visual search, filtering, multiple-action monitoring (dual task), and multiple-object tracking. It is our view that differential performance on these tasks reflects the presence of two underlying dimensions of attentional selection (Trick, Enns, Mills, and Vavrik, 2004).

One concerns the issue of awareness and involves the distinction first made by Shiffrin and Schneider (1977) between automatic and controlled processes. Specifically, there are two ways that a selection process might work. First, stimuli and responses might be selected without awareness. Selection without awareness has been called preattentive, inattentional, subconscious, unconscious, and unintentional by different authors, but regardless, this type of selection is automatic. Automatic selection is rapid, effortless, and unconscious, and is difficult to stop or modify once initiated. These processes are triggered by the presence of certain stimuli in the environment, and they run to completion without interfering with other processes. Second, stimuli and responses might be selected deliberately with awareness. Selection with awareness (variously called attentive, conscious, or intentional) involves controlled
Processing, which is to say that selection is effortful and slow, but it can be started, stopped, or modified at will, a feature that makes this type of processing flexible and intelligent. Controlled processes can cause changes in long-term memory through learning, and with adequate practice some types of controlled process may even become automatic. The fundamental problem with controlled processing is that it is difficult to carry out several controlled processes at once. Though the distinction between automatic and controlled processing is often discussed as if it were a strict dichotomy, we believe that it is probably more useful to consider it a continuum. Some processes are more automatic than others in the sense that they are initiated more quickly, require less effort, are more likely to be evoked unintentionally in a given situation, and are thus more difficult to bring under deliberate control.

The second dimension in the framework concerns the origin of the process, whether it is innately specified and thus common to all (exogenous) or engendered by a person’s specific goals and thus idiosyncratic (endogenous). Exogenous selection occurs as a result of the way humans are built: the nervous system is structured to respond preferentially so that there is an innate continuum of salience, with some stimuli and responses more likely to receive exogenous selection than others. In contrast, endogenous selection results from what people know about an environment and what they want to achieve, and it is thus idiosyncratic and situation-specific. People actively search the environment for information relevant to their specific goals or intentions and perform these tasks in ways that are consistent with their own expectancies and previous learning. These expectancies may act as a form of “perceptual set” causing people to look for specific objects at certain locations.

Considering attention in this way explains findings within the driving literature that otherwise might not be explained. As well, it clarifies a confusion that exists within both the basic and applied literatures: the conflation of the distinction between automatic and controlled processes with the distinction between exogenously triggered and endogenously initiated processes. We believe this confusion has caused some issues to be neglected, particularly those relating to how innately determined (exogenous) factors that affect human behavior in general might influence attentional selection when driving, as will be discussed next.

4.3 Four Modes of Attentional Selection

The combination of automatic and controlled processing with exogenous and endogenous selection produces the framework shown in Figure 4.1. In this framework, two forms of selection involve automatic processes. We call these reflex and habit. Reflexes of selection are automatic processes that are innately specified and triggered by the presence of certain stimuli in the environment. These processes initiate effortless, unconscious, and obligatory responses that occur even when inappropriate. Reflexes are not learned and consequently they cannot be unlearned. At best, when a reflexive process is counterproductive, the response can be reduced in intensity or “undone” after the fact, but in most cases this requires controlled-endogenous processing.

Habits are processes that come into existence when the operations necessary to fulfill a certain goal are carried out so often in a certain stimulus context that the processes become automatic and are carried out as soon as the person is in that
context. Although habits are the basis of skilled behavior, they can be problematic. If a habit is strongly associated with a specific situation, once an individual is in that situation it will require effort and planning (controlled-endogenous processing) to avoid acting in accordance with the habit. There are similarities between reflexive and habitual selection, but they differ in two important ways. First, though both are “triggered” by the presence of certain stimuli; the triggers for reflexes are innately set, whereas triggers for habits are learned, and this makes habits idiosyncratic and reflexes common to all. Second, a developmental timetable determines when reflexes emerge, but they are stable once acquired. Habits can be formed at any time and can also be replaced or fade at any time due to lack of practice or new learning. In the continuum of automaticity, where some processes are more automatic than others, reflexes retain their position near the extreme end of the automaticity continuum, whereas habits change their level of automaticity based on the frequency and recency of practice.

The other two modes of performance are controlled (exploration and deliberation). Exploration is the default mode for controlled processing—a type of selection that is carried out in absence of a specific task goal. Instead, exploration involves a generic goal—one common to all human beings in any environment—to maximize the acquisition of new information. Confronted with a new environment, humans find exploration of it rewarding in itself. Cognitive neuroscientists have recently linked this behavioral tendency of humans to the neurochemical finding that areas in the brain that are used to process visual information are arranged in a hierarchy, with natural opiates (chemicals linked to the experience of pleasure) present in only small amounts in the areas used for the simple registration of information, but present in increasingly larger amounts in areas used in the comprehension and interpretation of images (Biederman and Vessel, 2006). Thus, there is a growing understanding that the human tendency to be both “infovores” and to be “pleasure seeking” are inextricably linked in the way we are wired. We argue that in the absence of specific goals, these innate preferences set the default for what is attended when humans explore new environments for which they have no specific expectations, that is, environments lacking the stimulus triggers necessary to evoke specific reflexes or habit. The generic goal to acquire new information can be overridden without undue effort or planning once an individual undertakes a specific goal. To date, there is little research on exploratory selection.
In contrast, there are many studies of deliberate selection. *Deliberate selection* involves the execution of a chosen attention-demanding process at the expense of other processes. This type of processing involves conscious goals that reflect an individual’s specific knowledge, plans, and strategies for a certain situation, and these goals determine what is selected. Deliberate processing is flexible and responsive to new information because it is conscious and internally directed. With this type of processing there is hope of changing behavior rapidly (within seconds) in response to symbolic information, such as an oral command or written message. Processes that involve deliberate selection are necessary whenever the situation is difficult or novel, and when unruly habits or reflexes must be brought under control. However, deliberate selection is noticeably effortful. Moreover, because controlled processes interfere with one another, processes that involve deliberation preclude general exploration and impede other deliberate processes.

In the following sections we will work through the four modes of selection, applying the framework to studies chosen to represent a range of topics in the driving literature.

### 4.3.1 Reflexive (Automatic-Exogenous) Selection

Certain stimuli initiate effortless, unconscious, obligatory responses that occur even when counterproductive. This type of selection is not learned and may even be present in the very young. Generally, bringing reflexive selection under control requires deliberate (controlled-endogenous) processes though in some cases it may be possible to learn to compensate using a habitual response if a deliberate compensation process is practiced often enough. Regardless, it is important to note that the reflexive response is always there. It must be brought under control by other processes if it is to be avoided.

There is little research in this area, and at present some of the clearest demonstrations involve visual illusions. These are cases where certain stimulus configurations are selected and processed to yield a percept at odds with reality. Processing is clearly automatic (because it occurs effortlessly, even when counterproductive and inaccurate), and it is exogenous (prompted by natural reactions to environmental stimuli). Hills (1980) described an accident-inducing “perceptual trap” created when two unconnected roads appear to be coextensive from the driver’s perspective due to automatic perceptual grouping processes (grouping by good continuation). Similarly, there is an illusion that causes vehicles to appear to be moving more slowly than they actually are when viewed through fog (Krekelberg, van Wezel, and Albright, 2006). Illusions can also be used to encourage safe driving, as shown by Shinar, Rockwell, and Malecki (1980) when they induced drivers to slow down on a dangerous curve by using transverse road markings that produced an illusion of speed.

Sudden luminance onsets can trigger automatic eye movements and the reassignment of the attentional focus (Theeuwes, Kramer, Hahn, and Irwin, 1998), and this can be understood as an example of reflexive selection. It occurs whether or not the onsets are predictive of future events (e.g., stimulus cues in covert orienting tasks) and is even evident in young children (Plude, Enns, and Brodeur, 1994). Moreover, overcoming this tendency requires deliberate (endogenous-controlled) processing—either advanced planning (deliberately directing attention to another location) or
compensation after the fact (Theeuwes et al., 1998). This finding has relevance given
the use of flashing lights on emergency vehicles and a recent suggestion that they also
be used in brake lights (Berg, Berglund, Strang, and Baum, 2007). Certain types of
auditory and tactile stimuli can be selected reflexively as well, and there are a num-
ber of researchers exploring the use of auditory and vibrotactile warnings to prevent
collisions (e.g., Abdelhame, Desroches, Famewo, Nonnecke, and Varden, 2006;
Desroches, Varden, Nonnecke, and Trick, 2007; Ho, Reed, and Spence, 2006).

There are also situations where reflexive selection guides response selection. For
example, there is literature on reflexive processing of faces, and it is interesting to
note that when drivers encounter cyclists, they reflexively direct their gaze towards
cyclists’ faces when trying to infer their intentions—a practice that can lead to prob-
lems (Walker and Brosnan, 2007). There are also cases where one action causes
the reflexive selection of another, as shown by an effect often observed by driving
instructors. Novice drivers tend to turn the steering wheel in the same direction
as they move their eyes, for example, steering to left when looking left. This can
cause crashes and drivers have to be trained not to do it. Controlling this reflexive
tendency seems to require attentional resources (deliberate selection). Readinger,
Chatziastros, Cunningham, Bulthoff, and Cutting (2002) showed that experienced
drivers also tend to steer in the direction of their gaze when they are required to
perform a secondary task. Because this tendency to steer in the direction of gaze
can even be seen in young children learning to drive tricycles, this may represent an
e x a m p le of a reflexive association between responses.

4.3.2 Habitual (Automatic-Endogenous) Selection

When a goal is enacted repeatedly, carrying it out can become habitual and uncon-
scious, and the processes associated with it may become effortless. When this occurs,
it becomes possible to carry out those operations while performing another task with
little interference. In fact, these habits are a large part of what is meant by driving
skills. Although habits are often thought of as overlearned actions, we propose that
there can be habits of stimulus selection as well, and these govern what type of infor-
mation is selected, and where, when, and how drivers scan the driving environment.

Novice drivers are extraordinarily prone to accidents and it is commonly believed
that this is partly because they lack automatized behaviors that form the basis of driv-
ing skill. This is supported by many studies that show experienced drivers have less
difficulty than inexperienced drivers when carrying out secondary tasks while driving
(e.g., Shinar, Meir, and Ben-Shoham, 1998). These problems are especially notable
in teen drivers, who are disproportionately at risk when there are passengers in the
vehicle, or when using in-vehicle devices such as cellular phones (Chen, Baker, Braver,
and Gouhua, 2000; Neyens and Boyle, 2007). Experienced drivers do not require as
much controlled processing to carry out the basic operations necessary for driving,
and as a result, they multitask with less deterioration to their driving performance.

When drivers learn to drive, one of the things that develop is ability to sense haz-
ards quickly and efficiently. Drivers develop habits of sensory selection that enable
them to automatically encode the safety-related aspects of a driving scene. As a re-
result, there is less change blindness (an inability to notice safety-related change in
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an image) in experienced drivers (e.g., Famewo, Trick, and Nonnecke, 2006). There is also evidence that with experience, road signs begin to cause automatic priming, not only for the appearance of the same sign but for the related road scene (Crundall and Underwood, 2001). In experienced drivers, this priming causes the same sign to be perceived more quickly and accurately when presented a second time, but it also causes faster recognition of the associated hazard on the road.

Although habits of selection can be helpful, they can also put drivers at risk. The most obvious examples involve cases where drivers import their well-developed habits into new situations that require different behaviors, as occurs when they drive in rented cars (Al-Balbissi, 2001) or foreign countries (Summala, 1998). Habits of stimulus selection form a perceptual set, which yields an advantage in familiar situations but a disadvantage in atypical situations, temporarily “blinding” drivers to things that run counter to their expectations—things in plain view. This can even occur when the object in question is as brightly colored as a police car. Langham, Hole, Edwards, and O’Neil (2002) found that experienced drivers were faster to detect the presence of a parked police than inexperienced drivers when the police car was in the standard position (angle parked) but they were slower than inexperienced drivers when the car was in a nonstandard (straight on) position (see also Most and Astur, 2007).

The driving environment is forgiving, insofar as collisions are rare, and dangerous practices typically do not produce adverse consequences on a day-to-day basis. As a result, bad habits can develop over time, reversing the positive effects of driver training. Duncan, Williams, and Brown (1991) noted that drivers who had received their license in the last year checked their mirrors more often than more experienced drivers and were also more likely to leave an adequate distance when following another car. Drivers may develop the habit of exceeding the speed limit when they drive. Conforming to speed restrictions seems to require deliberate (controlled-exogenous) processing because secondary tasks interfere (Recarte and Nunes, 2002).

4.3.3 Exploratory Selection

Exploratory selection governs where attention goes when there is no specific task goal. Driving researchers were among the first to notice the importance of exploratory selection. Hills (1980) observed that experienced drivers, when not fully occupied with the driving task, look away from the relevant driving-related information and explore roadside advertising, low-flying planes, trees, etc. It may be impossible to prevent exploratory selection (Hughes and Cole, 1986; Smiley, 1994). If driving does not require drivers’ full attention, they devote their attention elsewhere.

What determines what things attract attention when an individual is exploring the environment without a specific goal? Although there has been relatively little research on this topic, Hughes and Cole (1986) noted that the “sensory conspicuity” of an object, its tendency to attract attention even when it is not deliberately sought, is determined in part by its retinal size, eccentricity, and contrast with the background. Crundall, van Loon, and Underwood (2006) found that street-level advertisements were most likely to divert eye movements than raised advertisements. The study of exploratory selection is relevant for the development of effective safety-related signs.
However, sometimes the stimuli that attract attention are inside the vehicle. Experimental selection is especially likely to occur in conditions of novelty, and this may explain why drivers spend disproportionate amounts of time looking at in-vehicle devices when they are new (e.g., Dingus, Hulse, Mollenhauer, Fleischman, McGhee, and Manakkal, 1997). These devices are often engineered with colorful, high-contrast displays to maximize legibility, and as a result they may compete successfully with extravehicular stimuli for exploratory selection. This may be particularly problematic if the display for the in-vehicle device is superimposed on the outside world, as occurs with “heads-up” displays. Tufano (1997) argues that the salience of heads-up displays interferes with a driver’s ability to see what is going on in the outside world, particularly when the outside events are unexpected.

4.3.4 Deliberate (Controlled-Endogenous) Selection

Deliberate selection is the most flexible and intelligent of all, and when driving, these processes are necessary in a variety of situations: (a) when conditions are challenging (low visibility, heavy traffic, unexpected events, unfamiliar environments); (b) when individuals perform unfamiliar activities or combinations of activities (dual tasks) that require an action plan to be constructed on line using moment-to-moment feedback from the environment; (c) when individuals are acting strategically, and not simply reacting to events in the immediate environment; (d) when individuals react to symbolic information that must be interpreted to be acted upon; and (e) when maladaptive habits and reflexes must be monitored and overcome.

There are a large number of studies relevant to deliberation, including those looking at the influence of secondary tasks such as using cellular phones (e.g., Horrey and Wickens, 2006) or using automated systems designed to provide drivers with information (e.g., Burnett, Summerskill, and Porter, 2004; Hampton and Langham, 2005; Stanton and Young, 1998). It is clear that when the resources for deliberate selection are focused on a task, it can produce prolonged inattentive blindness for things in plain view—as occurred when a road crew inadvertently paved over the carcass of a deer (see Most, Scholl, Clifford, and Simons, 2005).

There are also a variety of studies that examine factors that reduce the resources available for controlled (deliberate) processing, such as alcohol and fatigue (e.g., Curtin and Fairchild, 2003; Mascord, Walls, and Starmes, 1995). Alcohol depresses neural activity, and thus has significant effects on a wide range of sensory, cognitive, and motor processes. However, controlled (deliberate) selection processes are especially vulnerable because they are the most time-consuming and demanding. Similarly, even before drivers fall asleep, fatigue affects deliberate selection as drivers begin to withdraw resources necessary for deliberate (effortful) selection. It has also been noted that automated systems that take over various aspects of the driving task may put drivers at risk because they encourage drivers to withdraw resources used for deliberate selection, thus leaving drivers “out of the loop” when the systems fail (Stanton and Young, 1998).
Factors related to deliberate selection also predict individual differences in crash risk, particularly among senior drivers. Several components of deliberate selection are affected by age (Plude et al. 1994): attention switching becomes more difficult (as shown by orienting tasks), attentional search is slowed, and dual-task interference is exaggerated. In addition, with age there are exaggerated reductions in “useful field of view” with increases in primary task complexity and number of distractors. There are also age-related reductions in both sensory and motor functioning in older adults. Nonetheless, it is factors related to deliberate selection that best predict accident risk (e.g., Ball and Owsley, 1991; Lundberg, Hakamies-Blomqvist, Almkuist, and Johansson, 1998).

Deliberate selection involves executive functions associated with the frontal lobes, and there have studies that look at the impact of frontal lobe damage on driving performance (e.g., Wikman et al., 2004). Similarly, one of the dominant accounts of attention deficit hyperactivity disorder suggests that individuals with attention deficit/hyperactivity disorder (ADHD) have deficits in frontal lobe function that cause them to be disproportionately at risk for accidents of all sorts, but most notably, accidents when driving (e.g., Barkley, 1997).

### 4.4 CONCLUSIONS

This way of understanding attentional selection has ramifications for policymakers and driving-safety professionals interested in reducing the number of traffic accidents. It is widely agreed that driver inattention is the cause of many vehicle crashes, and, generally speaking, there are two approaches that might be used to prevent such crashes: either modify the driving environment (change road and vehicle design) or modify the drivers so that they change their behavior (induce them to change their personal goals, expectations, knowledge, and behavioral repertoire). The framework proposed here provides a straightforward way of identifying problems best remedied with environmental interventions and those that require behavioral interventions. The origin of the process (exogenous vs. endogenous) determines what type of intervention will work best. Problems originating from exogenous selection are most effectively dealt with using environmental solutions; it is better to work with the nervous system than against it. Problems relating to endogenous selection will be more amenable to behavioral solutions.

There are also implications for determining the type behavioral intervention that will be most effective. Automatic (habitual) and controlled (deliberate) processes respond best to different types of intervention. Behavioral interventions that involve aversive or pleasant stimuli in the immediate driving environment will be most effective with habits. If the problematic behavior is the result of deliberate selection then there is hope for interventions that involve attitude change, education, and long-term penalties and incentives (providing the driver is not suffering from some form of frontal lobe dysfunction). Maladaptive driving behaviors are often maintained by both habit and deliberation, and consequently two-level interventions may be necessary.
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