DRIVING AND SELECTIVE ATTENTION: A CONCEPTUAL FRAMEWORK FOR UNDERSTANDING THE ROLE OF SELECTIVE ATTENTION IN DRIVING

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Although driver inattention is thought to cause many vehicle crashes, the research is fragmented. The goal of this paper is to provide a framework to unify the research – a framework based on the combination of two fundamental dimensions of attentional selection: (a) selection with and without conscious awareness (controlled and automatic), and (b) selection by innately determined and internally self-directed cognitive mechanisms (exogenous and endogenous). The model posits four modes of selection. Two involve automatic processes: reflex (automatic-exogenous) and habit (automatic-endogenous). The other two modes involve controlled processes. We refer to these modes as exploration (controlled-exogenous) and deliberation (controlled-endogenous). This framework reveals links between factors within the experimental research on driving, including the effects of secondary tasks (e.g. cell phone use), fatigue, and alcohol. There are also ramifications for the differential crash rate literature, studies of automated systems that provide drivers with information, and strategies for crash-prevention.

1. INTRODUCTION

Driver inattention is thought to cause many crashes and the concept of selective attention is fundamental to important theoretical constructs in the cognitive ergonomics literature, including situational awareness and mental workload (see Trick et al, in press). The goal of this paper is to provide a framework to unify the literature, a framework that draws together diverging threads, revealing directions for future research and ramifications for interventions designed to reduce the number of crashes. Because of the breadth of this framework, it will be impossible to review all the relevant literature here. Instead, we will summarize fundamental features of the framework, highlighting findings that exemplify key principles. This paper will be 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; the third touches on practical implications for crash-prevention.

Selective attention is thought to be necessary because there are too many things in the environment to perceive and respond to at once. However, at present there is no general theory of selective attention in the basic research. 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. 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 to certain stimuli preferentially, so that there is an innate continuum of stimulus salience, with some types of stimuli 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 expectations 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 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 behaviour in general might influence attentional selection when driving, as will be discussed below.

2. FOUR MODES OF SELECTION

The combination of automatic and controlled processing with exogenous and endogenous selection produces the framework shown in Figure 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, 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. \textit{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 behaviour, 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 on the automaticity continuum, whereas habits change their level of automaticity based on the frequency and recency of practice.

![Diagram](image)

Figure 1. A framework for understanding varieties of selective attention involved in driving

The other two modes of performance are controlled (exploration and deliberation). \textit{Exploration} is the default mode for controlled processing, a type of selection that is carried out in absence of specific goals. Instead, exploration involves a generic goal -- one common to all human beings in any environment. Exploration requires controlled processing because full object recognition
generally requires attention. We argue that in the absence of specific goals, innate preferences set the default for what is attended when humans explore environments that they have no specific expectations about, environments lacking the stimulus triggers necessary to evoke reflex or habit. These generic defaults can be over-ridden 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 in turn, applying the framework to studies chosen to represent a range of topics in the driving literature.

### 2.1 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 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 percep at odds with reality. Processing is clearly automatic (because it occurs effortlessly, even when counter-productive and inaccurate), and it is exogenous (prompted by natural reactions to environmental stimuli). Hills (1980) described an accident-inducing ‘perceptual trap’ created when two non-connected roads appear to be coextensive from the driver's perspective due to automatic perceptual grouping processes (grouping by good continuation). 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 re-assignment of the attentional focus (Theeuwes et al 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, & 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 current practice of using bright flashing lights on emergency vehicles.
There may also be 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: steering to left when looking left, for example. 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 et al. (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 example of a reflexive association between responses.

2.2. Habitual (automatic-endogenous) selection

When a goal is enacted repeatedly, carrying it out can become habitual and unconscious, 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 over-learned actions, we propose that there can be habits of stimulus selection as well, and these govern what type of information 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 automaticized behaviours that form the basis of driving skill. This is supported by many studies that show experienced drivers have less difficulty than inexperienced drivers when carrying out secondary tasks while they drive (e.g., Shinar, Meir, & Ben-Shoham, 1998). This result suggests that experienced drivers do not require as much controlled processing to carry out the basic operations necessary for driving.

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 behaviours, as occurs when they drive in rented cars (Al-Balbissi, 2001) or foreign countries (Summala, 1998). As well, some of the habits that develop with practice are bad habits. 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-endogenous) processing because secondary tasks interfere (Recarte & Nunes, 2002).

2.3. Exploratory (controlled-exogenous) selection

Exploratory selection governs where attention goes when there is no specific 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, trees, etc. It may be impossible to prevent exploratory selection (Hughes & 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. The study of exploratory selection is relevant for the development of effective signs.

However, sometimes the stimuli that attract attention are inside the vehicle. Exploratory 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 et al 1997). These devices are often engineered with colorful, high contrast displays to maximize legibility and as a result they may compete successfully with extra-vehicular 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.

2.4. 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; (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., Strayer, Drews, & Johnston, 2003) or using information provided by automated systems designed to help drivers (e.g., Stanton & Young, 1998). Other studies examine factors that reduce the resources available for controlled (deliberate) processing, such as alcohol and fatigue (e.g., Mascord, Walls & Starmes, 1995).

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; 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, in general, it is factors related to deliberate selection that best predict accident risk (e.g., Ball & Owsey, 1991; Lundberg et al, 1998).

3. INTERVENTIONS FOR CRASH-PREVENTION

Finally, this way of understanding attentional selection has ramifications for policy-makers 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 behaviour (induce them to change their personal goals, expectations, knowledge, and behavioural
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 behavioural solutions.

There are also implications for determining the type behavioural intervention that will be most effective. Automatic (habitual) and controlled (deliberate) processes respond best to different types of intervention. Behavioural interventions that involve aversive or pleasant stimuli in the immediate driving environment will be most effective with habits. If the problematic behaviour is the result of deliberate selection, there is more hope that interventions that involve attitude change, education, and long-term penalties and rewards will have an effect. Maladaptive driving behaviours are often maintained by both habit and deliberation, and consequently dual-mode interventions may be necessary.

REFERENCES


