see and recognize signs in very short time durations was somehow related to semantic differential measures of stored meaning). Data that the authors will report elsewhere clearly show that sign detection, recognition, and action decision latency are all clearly related to sign meaning. However, for this report, the authors computed a total of 1,152 correlations between laboratory tests of perception and 12 semantic differential meaning scales and so few were found to be significant that it is clear that semantic differential measures of attributed meanings of a sign are not systematically related to laboratory tests of the ability to detect, recognize, and decide on driver actions. The clear suggestion of these findings is that the semantic differential, as an adjunct and verification device for laboratory detection/recognition research is of questionable reliability and validity.

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Drivers' Unconscious Errors in the Processing of Traffic Signs

LESLIE A. WHITAKER

ABSTRACT

Human information processing is divided into two processing modes. One is a conscious, attention-demanding method that is flexible and can be readily controlled. The second is an unconscious, essentially uncontrolled processing that is triggered by well-practiced stimulus-response associations. This paper contains a description of two types of errors to which unconscious processing is prone: illusory combinations of display elements and interference from conflicting irrelevant display elements. Traffic guide signs that may be susceptible to unconscious (automatic) processing errors are also presented as well as research results that are consistent with the hypothesized errors.

Unconscious behaviors during driving are a common experience for some motorists. A person may drive a familiar route and arrive at the destination without being aware of the frequent turns and stops along the way. Drivers are most often aware of this unconscious behavior when they have intended to alter a familiar route by stopping, for example, at the golf course or the gas station. Then, they arrive at the office after having missed the intended stop completely.

Well-learned tasks move from attention-demanding ones to the effortless nature of automatic unconscious processing. This processing is susceptible to a different set of problems than is conscious processing. Driving is a task that may be particularly susceptible to the tricks of automatic processing because it is so well-practiced.

Study of the unconscious was an active area of investigation early in this century (1). It fell subsequently into disfavor and it has been only re-

TABLE 4 Semantic Differential Scale Correlations with Decision Reaction Results by Sign Shown

	Signal Ahead (Sym)	Signal Ahead (Word)	Stop Ahead (Sym)	Stop Ahead (Word)	Do Not Enter (Sym)	Do Not Enter (Word)	Stop (Oct)	Stop (Diam)
Good - Bad								
Perf Same	--	--	--	--	--	--	--	--
Perf Opp	--	--	--	--	--	--	--	--
Familiar - UNF								
Perf Same	--	--	--	--	--	-0.55	--	--
Perf Opp	--	--	--	--	--	-0.55	--	--
Active - Passive								
Perf Same	--	--	--	--	--	-0.61	--	--
Perf Opp	--	--	+0.36	+0.44	--	-0.49	--	-0.43
Pred - Unpred								
Perf Same	--	--	--	--	--	--	--	--
Perf Opp	+0.42	--	--	--	--	--	--	--
Beautiful - Ugly								
Perf Same	--	--	--	--	--	--	--	--
Perf Opp	--	--	--	--	--	--	--	--
Mean'ful - Mean'less								
Perf Same	--	--	--	--	--	--	--	--
Perf Opp	--	--	--	--	--	--	--	--
Fast - Slow								
Perf Same	--	--	--	--	--	--	--	--
Perf Opp	--	--	--	--	--	--	--	--
Strong - Weak								
Perf Same	--	--	--	--	--	--	--	--
Perf Opp	--	--	--	--	--	--	--	--
Val - Worthless								
Perf Same	--	--	--	--	--	-0.58	--	--
Perf Opp	--	--	--	--	--	-0.45	--	--
Imp - Unimp								
Perf Same	--	--	--	--	--	--	--	--
Perf Opp	--	--	--	--	--	--	--	--
Sharp - Dull								
Perf Same	--	--	--	--	--	--	--	--
Perf Opp	--	--	--	--	--	--	--	--
Simple - Complex								
Perf Same	--	--	--	--	--	--	--	--
Perf Opp	--	--	--	--	--	--	--	--

"--" = Not significant at 0.05 or better level.

Perf Same = detection, recognition or decision-reaction performance on sign with same lexical status to legend as the one scaled.

Perf Opp = detection, recognition or decision-reaction performance on sign with opposite lexical status in legend as the one scaled.

32ms and 49ms = milliseconds exposure duration in tachiostoscopic presentation during recognition experiment, etc.

cently that cognitive psychologists have again turned their hand to study the effects of unconscious processing in automatic behavior (2-5). This research has inadvertently produced a significant body of data dealing with automated or nonconscious processing. For example, the development of skill with practice results in a decrease in time, effort, and attention needed to complete a task (6). The consequence is that the skilled operator can apply more cognitive resources to the execution of concurrent subsidiary tasks while well-practiced tasks are run by automated processes (7). The development of time-sharing skills for the dual tasks of copying text while memorizing unrelated material was reported by Spelke et al. (8). After 17 weeks of practice, two subjects learned to execute these two tasks concurrently without interference.

Drivers develop similar time-sharing skills with experience. The new driver concentrates effort on the guidance task, and is later able to add some navigation and route-finding tasks, but only after some weeks of practice can this novice converse comfortably with a passenger while driving through relatively uncongested streets. Even after years of practice, an experienced driver may ask passengers to stop conversing when particularly difficult winter driving conditions exist. The driving task under these adverse conditions again demands full attention. It is no longer sufficient to allocate even the guidance tasks to well-practiced, possibly automated processing.

These anecdotal experiences are supported by recent reports from cognitive psychology. Posner has described automatic processing and emphasized its resistance to change (3). He described conscious processing as requiring attention and as being quite flexible and amenable to change. In contrast, automatic processing places little or no burden on attention but is essentially hardwired (through physiology or practice) and very resistant to modification. For example, Shiffrin and Schneider trained a group of subjects to respond _yes_ to various shapes (6). After 2,100 trials, the subjects could respond to sets containing one or two different items with speed equal to that of larger sets of items. Processing speed was independent of the amount of information to be processed. Subjects reported that the positive stimuli seemed to "jump out of the display." They were not conscious of having to search the display for positive items. These are characteristics that describe automated processing developed by practice. These same subjects subsequently were retrained to respond _no_ to the formerly positive set. Almost 1,000 trials were necessary to remove the previously learned positive response.

After these 1,000 trials, the subjects' response times had returned to baseline. The response times for the new positive set did not yet show the independence of information load (set size) characteristic of automatic processing. Automatic processing is very resistant to change.

Posner and Snyder have defined the criteria for automatic processing: Automatic processing occurs without conscious awareness and without interfering with other concurrent processing activities (9). The results of automated processing may actually interfere with the appropriate response to a concurrent task.

Dewar has tested this problem with traffic signs (10). Prohibited-turn signs are a combination of a directional arrow plus a prohibited symbol (see Figure 1). Dewar argued that the subject's prepotent response to the directional arrow is to respond in the direction of the arrow. The negation (prohibition) of this action is a time-consuming and error-prone process. The prepotent, overlearned response

FIGURE 1 Prohibited left-turn sign and components.

of going with the direction of the arrow interferes with the designated correct response. For permissive signs, arrows indicate the permitted direction(s) and a redundant green circle indicates permission (see Figure 2).

Treisman and her associates have proposed a mechanism that predicts errors when combinations of sign

FIGURE 2 Permitted straight-ahead and right-turn sign and components.

elements (e.g., arrow plus contradiction qualifier) are necessary to interpret the sign's meaning (2,11,12). These errors are predicted for conditions in which automatic, instead of conscious, processing occurs. In a series of laboratory conditions, Treisman has established that it is the combination of visual features that requires attentional resources for successful processing. When these resources are withdrawn from processing the display, errors result in illusory combinations of separate features. For example, a display containing an array of ⌉'s and /'s will be seen as an array containing ⌉/'s. In addition, ⌉/ may be decomposed into ⌉ + /. These errors occur when the subject's attentional resources are withdrawn to a second concurrent task. The automatic processing of the first task's feature components can still be accomplished. However, the correct combination of those features into the displayed objects is impaired without conscious attention-demanding) processing.

An experienced operator seems to be doing much of the driving as an automatic process by the Posner and Snyder definition (9). Therefore, observation and processing of standard highway guide signs may be impaired in ways predicted for the automatic mode. The combination of component features will be vulnerable to error. Some traffic signs are more prone to combinatoric problems by the very nature of their content. For example, the prohibited-turn sign requires the accurate combination of components: arrow plus red circle and a slash. The combination gives the message. Losing either component or combining them incorrectly can lead to driving errors.

At especially difficult intersections, a redundant system is sometimes employed. On the same stanchion, one sign shows the prohibited left turn, whereas the sign immediately below displays a one-way right arrow (see Figure 3). Erroneous combinatorics would be especially disastrous here. It is relevant that this double signing is used to control intersections prone to a left-turn error; intersections where the driver's preconception, preoccupation with other aspects of driving, or road condi-

FIGURE 3 Prohibited turn onto one-way street.

tions make automatic processing the most likely mode to be applied to this sign's perception.

A benefit of automatic processing is that limited attentional resources are made available for processing subsidiary tasks; however, a correlate of this benefit is that automatic processing is not controlled by attention, effort, or direction from the operator. Posner states that automatic processing runs its course from stimulus to response without attentional control (9,13). The input stimulus triggers the automatic processing. If the output of this processing is advantageous for the conscious task, then performance may be augmented. However, if the automatic output is contrary to the goal of the conscious task, then a decrement occurs. A classic example of such interference was originally reported by Stroop (14). Observers were asked to say the color in which a word was printed. For example, the word "great" was printed in red ink so the correct response was "red." In one condition, noncolor words were printed. In the other condition, the names of colors were printed. Color names were never written in the same ink color as their name (e.g., "green" was printed in red ink). Observers responded much more slowly when the words printed were the names of colors than when they were noncolor words. The experimenter had manipulated the task to produce conflict between the automatic process of reading the printed word and the conscious task of naming the color in which the words were printed. When the printed word was in the same category (color) as the response word (ink color), the output of the automatic processing conflicted with the required response of the conscious processing and response time increased.

This "Stroop effect" has been studied for a variety of tasks and is an experimental paradigm used to measure the conflict between unintended automatic processing and the conscious task's intended processing. The Stroop phenomenon for processing traffic guide signs is illustrated in two recent studies by Whitaker and Sommers, and Whitaker, respectively (15,16). In these studies, airport guide signs were used. Each sign consisted of a pictograph (a swept wing jet aircraft) indicating an international airport plus an arrow tab indicating the airport's direction. The direction of the plane symbol and the direction of the arrow could either agree, be orthogonal, or disagree (see Figure 4). Subjects were fastest and produced the fewest errors when the plane and the arrow agreed. Orthogonal pairing produced intermediate performance, and disagreement between plane and arrow produced the worst performance.

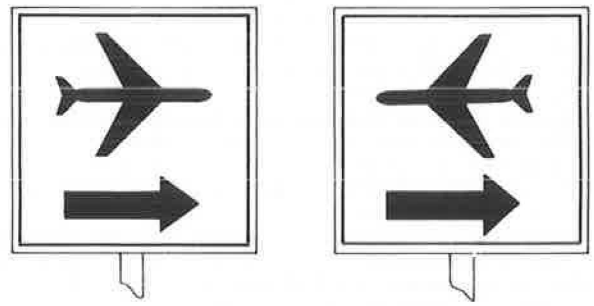

FIGURE 4 Airport guidance signs with airplane symbol plus guidance arrow.

These results were interpreted in the following way. Automatic processing of both components of the sign took place. The strong directional information from the plane symbol augmented the arrow information for agreement signs. Responses to these signs, consequently, were faster than under the baseline (orthogonal) condition. Disagreement between plane and arrow on the bipolar dimension left-right meant that both responses were triggered. The subject had to suppress the incorrect (plane) direction and output the correct (arrow) direction. This conflict produced the poor performance for disagreement signs.

One recent study of traffic accidents concluded that human error was implicated as the definitive cause of 70 percent of the accidents. Half of these errors were information processing failures of perception or comprehension [Treat (17)].

This paper concentrates on possible sources of error specific to the automatic processing mode. This mode (in combination with attentional information processing) is a mode frequently used for well-learned, highly practiced tasks such as driving. Research has provided helpful guidelines for signing standards and current guidelines are based on knowledge of conscious information processing. In establishing traffic signing standards, it will also be beneficial to be aware of the unique pitfalls produced by our unconscious (automatic) cognitive behaviors.

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Abridgment

Recognition Errors Among Highway Signs

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ABSTRACT

Forced choice recognition errors were examined for tachistoscopic presentations of four sign messages (Stop, Go Right, Go Left, Slow Down) displayed in word versus symbol format. Sign exposure durations were 1, 2, and 3 standard deviations (32, 41, and 49 msec) above the mean exposure duration for chance-level presence or absence detection of a traffic sign in the visual field (24 msec). As exposure duration increased, recognition errors decreased more rapidly for Stop message signs than for other messages. Word versus symbol format differentially influenced reductions in recognition errors for Right, Left, and Slow messages but had little influence on errors on Stop message signs. Several pairs of signs were shown to be reciprocally confused with each other, and Merge Right signs were frequently confused with signs presenting three different action messages. For the signs tested, those that are likely to produce recognition errors resulting in accidents were identified as well as those for which recognition errors are unlikely to produce accidents.

The present research was prompted by two major concerns. One concern was the pragmatic concern of civil engineers interested in effective traffic signing to safely guide traffic flow. The second was the theoretical need to discriminate between (a) the purely perceptual operations performed by the brain in extracting sign information and (b) the mental operations involved in driver actions that occur after the recognition process is completed.

The research was initiated by a focus on the failure of drivers to recognize and properly respond to the symbol legend Stop Ahead standard sign W3-1a