VISUAL COGNITION, 2007, 15 (2), 125–132

Psychology Press
Taylor & Francis Group

Feature-based attentional set as a cause of traffic accidents

Steven B. Most
University of Delaware, Newark, USA

Robert S. Astur
Institute of Living at Hartford Hospital, and Yale University School of Medicine, New Haven, USA

Voluntary and relatively involuntary subsystems of attention often compete. On one hand, people can intentionally "tune" attention for features that then receive visual priority; on the other hand, more reflexive attentional shifts can "short-circuit" top-down control in the face of urgent, behaviourally relevant stimuli. Thus, it is questionable whether voluntary attentional tuning (i.e., attentional set) can affect one's ability to respond to unexpected, urgent information in the real world. We show that the consequences of such tuning extend to a realistic, safety-relevant scenario. Participants drove in a first-person driving simulation where they searched at every intersection for either a yellow or blue arrow indicating which way to turn. At a critical intersection, a yellow or blue motorcycle—either matching or not matching drivers' attentional set—suddenly veered into drivers' paths and stopped in their way. Collision rates with the motorcycle were substantially greater when the motorcycle did not match drivers' attentional sets.

The visual world is abundant and complex, but the brain's processing capacity is limited. As a result, visual stimuli continually compete for processing resources. When important information loses out, the consequences can be lethal. Unattended stimuli often go unnoticed (Chun & Marois, 2002; Mack & Rock, 1998; Most, Scholl, Clifford, & Simons, 2005b; Simons & Chabris, 1999), and traffic accident reports often tell of drivers

Please address all correspondence to Steven B. Most, Department of Psychology, 108 Wolf Hall, University of Delaware, Newark, DE 19716-2577, USA. E-mail: most@psych.udel.edu

We thank M. Chun, D. Simons, B. Scholl, and K. Curby for helpful comments and discussion. Portions of this paper were presented at the 2005 meeting of the Vision Sciences Society. This research was conducted at Yale University, where S. Most was supported by NIH grant F32 MH066572.

http://www.psypress.com/viscog DOI: 10.1080/13506280600959316

failing to see or respond to seemingly obvious obstacles (e.g., McLay, Anderson, Sidaway, & Wilder, 1997). Attempts to increase visibility tend to focus on stimulus-based factors such as daytime headlights or joggers' reflective vests, and indeed, certain types of features seem especially capable of grabbing attention (Franconeri & Simons, 2003; Theeuwes, 1992; Yantis & Jonides, 1984). Yet, neuroscientific and behavioural evidence raise the possibility that attentional priorities brought by a perceiver to a situation can contribute to conspicuity at least as much as stimulus properties do.

When an individual seeks or prepares to respond to specific visual features—i.e., establishes an *attentional set*—strong interconnections between prefrontal cortical areas (implicated in working memory) and visual areas such as the inferior temporal cortex (IT) allow attentional set to modulate stimulus-linked responsiveness in the latter regions (Desimone & Duncan, 1995). For example, when monkeys prepared to respond to a target, IT neurons optimally responsive to the target's properties showed elevated activity even in the delay period before the target appeared (Chelazzi, Miller, Duncan, & Desimone, 1993). Even when a stimulus is unexpected or not the target of a search, the degree to which it matches an individual's attentional set influences the attentional priority it receives. When monkeys were required to shift their gaze from fixation to a predetermined target, they were significantly more likely to make erroneous saccades to distractors sharing a property with the target (Bichot & Schall, 1999). Meanwhile, neurons in the frontal eye field, involved in oculomotor control, were more responsive to distractors in their receptive field that were similar, rather than dissimilar, to the target (Bichot & Schall, 1999). Behaviourally, the degree to which distractors interfere with target search (Duncan & Humpheys, 1989), capture attention (Folk, Remington, & Johnston, 1992), or are noticed (Most et al., 2005b; Most et al., 2001), increases with their similarity to targets kept in mind.

However, when unexpected obstacles appear in realistic, safety-relevant scenarios, such as driving, it is unclear whether effects of attentional set—so evident at the neural level and in simplified laboratory tasks—would influence rates of accidents. For example, a second attentional network, incorporating predominantly the right-lateralized ventral frontal cortex and temporoparietal junction, has been suggested to function as a "circuit breaker", automatically reorienting attention to unexpected, behaviourally relevant stimuli (Corbetta & Shulman, 2002). Indeed, dynamic, looming stimuli have been found to capture attention, leading to the suggestion that behaviourally urgent stimuli are particularly likely to divert attention (Franconeri & Simons, 2003). Because unexpected obstacles are relevant, urgent, and often looming when driving, such mechanisms could negate the influence of attentional set.

Driving is an everyday task that is particularly well suited to elucidating both basic cognitive mechanisms and their functional consequences (e.g., Strayer, Drews, & Johnston, 2003; Trick, Enns, Mills, & Vavrik, 2004; see also Leibowitz, 1996). To assess whether attentional set plays a role in safety-relevant situations where unexpected obstacles are important for the task at hand, our participants drove through a virtual city using a steering wheel and pedals. Each intersection contained a road sign with yellow and blue arrows, and participants were instructed that they were either always to follow a blue arrow or always to follow a yellow arrow. Thus, half the participants adopted an attentional set prioritizing yellow cues and half prioritized blue cues. At a critical intersection, a motorcycle travelling towards the driver from the opposite direction veered suddenly and stopped directly in the driver's path. The motorcycle was either yellow or blue, so that it either matched ("match" condition) or did not match ("mismatch" condition) participants' attentional sets. We recorded latency to brake for the motorcycle and rates of colliding with it in order to assess the impact of attentional set in such a scenario.

METHOD

Participants

Seventy-three individuals at Yale University participated in the experiment, but fourteen were discarded because their performance did not meet predetermined criteria. Specifically, to ensure that participants knew how to brake and were not dispositionally unlikely to slow for obstacles, the third intersection (out of 10) contained pedestrians who crossed in front of the vehicle. Seven participants who failed to brake for the pedestrians were discarded from the analyses. Additionally, in order to ensure that participants were properly attending to arrows in the final, critical intersection, only those participants who turned in the correct direction at that intersection were analysed. Seven additional participants were discarded because they missed the final turn. An additional three participants were discarded: Two because the vehicle did not maintain a constant speed during the session and one who had trouble enough navigating through the environment that the experimenter temporarily took the wheel. The remaining 56 participants (30 male; mean age = 21.3 years) were distributed equally in the two match conditions (yellow arrows with yellow motorcycle; blue arrows with blue motorcycle) and two mismatch conditions (yellow arrows with blue motorcycle; blue arrows with yellow motorcycle) (see procedure below). The distribution of males and females was roughly equal, with 12 females across both match conditions and 14 across both mismatch conditions. Informed consent was obtained from all participants, as approved by the Institutional Review Board at Yale University.

Procedure

The high-resolution driving simulation was run on a Dell Latitude Laptop with a 17-inch display. Participants used a table-mounted Logitech Momo force-feedback steering wheel with accompanying foot pedals to navigate through a virtual cityscape, designed via custom-developed software.[1] During the practice session, participants drove through a city identical to that in the experimental phase, except that all signs, pedestrians, and other vehicles were absent.

For the experimental phase, the vehicle automatically maintained a 30 mph velocity, and participants were instructed to brake only to avoid collisions with other vehicles or pedestrians. Each intersection contained a road sign with arrows pointing left, right, and straight ahead; upon approach, the arrows began briefly and regularly to flash yellow and blue in different configurations (500-ms/flash), such that any arrow's colour on one flash was not necessarily the same as that on the next flash. Participants were instructed that, upon a final, sustained flash, they were either always to follow a blue arrow or always to follow a yellow arrow (depending on the between-subjects condition, the final flash always displayed either one blue arrow among yellow arrows or one yellow arrow among blue arrows; this configuration was sustained until drivers passed the sign). Flashing arrows were used to ensure that participants maintained an attentional set, unsure of when the final flash would appear.

Almost immediately after participants passed through the ninth, penultimate intersection, they crossed over an invisible trigger that simultaneously released the motorcycle towards them from up ahead and started a millisecond timer on the computer. Just as participants reached the tenth intersection, the motorcycle did as well, and it unexpectedly veered and came to a crawl directly in the driver's path. The motorcycle was either blue or yellow, so that it either matched or did not match drivers' attentional set (see Figure 1A).

To ensure that drivers in the match and mismatch conditions did not differ in the rate with which they approached the final intersection, an additional check was incorporated: Before reaching the final intersection, participants passed over two invisible markers and the time at which they did so was recorded. The two groups did not differ in this respect; therefore, any differences in braking latency and collision rate at the final intersection

[1] Software enquiries can be directed to the second author at robert.astur@yale.edu

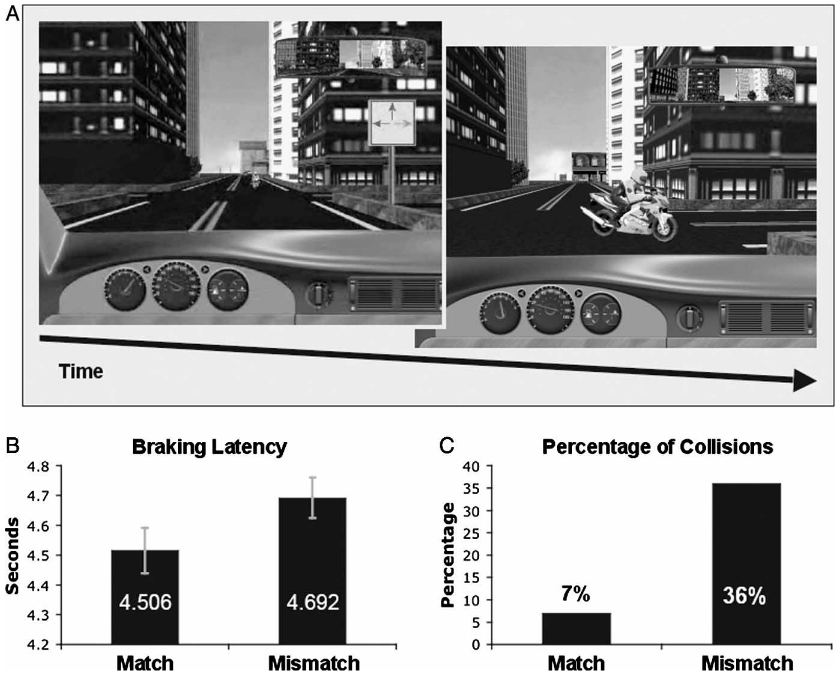

Figure 1. Braking latency and collision rate depended on attentional set. (A) Still-frames from the final intersection in a match condition. (B) When the colours of the motorcycle and the attended arrow did not match, participants braked 186 ms later than when the colours matched (measured from onset of a timer to first application of the brakes, as shown here with standard error bars). (C) Participants were also significantly more likely to collide with the motorcycle in the mismatch than in the match condition. The two conditions contained equal numbers of participants, with roughly equal number of males and females in each condition ($N = 56$).

would not be attributable to pre-existing differences in driving performance on the preceding stretch of road. Collisions were registered when the motorcycle came within three virtual feet in front of the "windshield" and were accompanied by a crashing sound.

Throughout the experiment, the experimenter stood several feet behind the participant and remained silent, except to notify participants when they had improperly applied the brakes (i.e., for any reason other than avoiding collisions) and to inform them when they missed one of the turns, in which case participants corrected themselves by making a U-turn and proceeding in the correct direction. The experimenter also silently noted the occurrence of collisions at the final intersection, as well as failures to brake for pedestrians at the third intersection or to make the final turn. Drivers' latencies to brake for the motorcycle were recorded by the computer.

RESULTS AND DISCUSSION

Drivers in the "mismatch" condition braked 186 ms later on average than those in "match" condition, $t(52) = 2.12$, $p = .038$, one-tailed (Figure 1B). The two groups also differed in their collision rates, with 7% (2/28) colliding with the motorcycle in the match condition and 36% (10/28) colliding in the mismatch condition, $\chi^2(1) = 6.79$, $p = .009$ (see Figure 1C).[2] Two participants failed to apply the brakes at all before colliding: Both were in the mismatch condition. Collision rates depended neither on the motorcycle's colour nor on the driver's sex, $p\text{s} > .45$.

These results reveal that, despite a proposed attention subsystem that interrupts voluntary control in the face of behaviourally urgent stimuli (e.g., Corbetta & Shulman, 2002), attentional set still affects the speed with which people can respond to unexpected obstacles in their way. It is important to note that this experiment is silent regarding the precise mechanism involved; for example, drivers' delayed reactions in the mismatch condition might have reflected either delayed perception of the motorcycle or simply delays at the motor output stage. Nevertheless, the strength of this effect is such that it emerged not only in response time differences, but also in the rates with which drivers collided with another vehicle. Had this been a real situation instead of a simulation, the consequences of these collisions could have been life threatening. Thus, to the degree that the simulation was immersive, the motorcycle possibly had an emotional quality to it as well. Emotional information has been found to disrupt the maintenance of attentional goals even when such information is task-irrelevant (e.g., Most, Chun, Widders, & Zald, 2005a; Pratto & John, 1991). However, the current results suggest that such effects may not negate the influence of attentional set.

These data have practical implications as well as theoretical ones. Within the traffic safety literature, much effort has been devoted to understanding the cognitive factors contributing to accidents (e.g., Cole & Hughes, 1984; Hole, Tyrrell, & Langham, 1996; Langham & Moberly, 2003). The importance of this endeavour cannot be overstated; for example, drivers' late detection of obstacles has been referred to as the most basic of driver errors (Rumar, 1990). Historically, emphases have been placed on stimulus-based contributions to conspicuity (e.g., distinctiveness), but our results strongly support more recent attempts to address drivers' immediate perceptual goals and expectations as well (see Langham & Moberly, 2003, for a review). Although the precise task used in this experiment—looking for flashing arrows—is somewhat removed from a typical driving scenario, it is not unusual for people to seek particular visual features while driving (e.g.,

[2] Even had no participants been discarded, the difference in collision rates between the match and mismatch conditions would have remained significant, $p < .05$.

monitoring orange traffic cones in anticipation of a lane shift). In situations where drivers' attentional sets may be especially amenable to manipulation, such as near roadside construction sites, safety engineers might consider how best to balance the distinctiveness of obstacles with their integration into the surrounding environment, where some features and objects already are the likely focus of peoples' attentional sets.

In sum, effects of attentional set extended to behaviour in a realistic, safety-relevant scenario, profoundly influencing the number of accidents that occurred. This is especially striking because the situation approximated an everyday task and the motorcycle was task-relevant; in real life, it would have been a source of danger. Although additional factors have yet to be explored (e.g., the relative effect of age and driving experience), it appears that attentional set wields substantial power even when the behavioural urgency of a stimulus might be predicted to override, or "short circuit", top-down attentional control (e.g., Corbetta & Shulman, 2002). From a practical standpoint, this finding does not entirely diminish the value of stimulus-oriented efforts to increase conspicuity; some stimulus properties may be advantaged in capturing attention in many situations, particularly in the absence of any overriding attentional settings (Yantis, 1993). However, in the numerous real-world cases where stimulus-based factors cannot sufficiently explain an accident, investigators might perhaps focus on the role of attentional set.

REFERENCES

Bichot, N. P., & Schall, J. D. (1999). Effects of similarity and history on neural mechanisms of visual selection. *Nature Neuroscience*, *2*, 549–554.

Chelazzi, L., Miller, E. K., Duncan, J., & Desimone, R. (1993). A neural basis for visual search in inferior temporal cortex. *Nature*, *363*, 345–347.

Chun, M. M., & Marois, R. (2002). The dark side of visual attention. *Current Opinion in Neurobiology*, *12*, 184–189.

Cole, B. L., & Hughes, P. K. (1984). A field trial of attention and search conspicuity. *Human Factors*, *26*, 299–313.

Corbetta, M., & Shulman, G. L. (2002). Control of goal-directed and stimulus-driven attention in the brain. *Nature Reviews Neuroscience*, *3*, 201–215.

Desimone, R., & Duncan, J. (1995). Neural mechanisms of selective visual attention. *Annual Review of Neuroscience*, *18*, 193–222.

Duncan, J., & Humphreys, G. W. (1989). Visual search and stimulus similarity. *Psychological Review*, *96*, 433–458.

Folk, C. L., Remington, R. W., & Johnston, J. C. (1992). Involuntary covert orienting is contingent on attentional control settings. *Journal of Experimental Psychology: Human Perception and Performance*, *18*, 1030–1044.

Franconeri, S. L., & Simons, D. J. (2003). Moving and looming stimuli capture attention. *Perception and Psychophysics*, *65*, 999–1010.

Hole, G. J., Tyrrell, L., & Langham, M. (1996). Some factors affecting motorcyclists' conspicuity. *Ergonomics*, *39*, 946–965.

Langham, M. P., & Moberly, N. J. (2003). Pedestrian conspicuity research: A review. *Ergonomics*, *46*, 345–363.

Leibowitz, H. W. (1996). The symbiosis between basic and applied research. *The American Psychologist*, *51*, 366–370.

Mack, A., & Rock, I. (1998). *Inattentional blindness*. Cambridge, MA: MIT Press.

McLay, R. W., Anderson, D. J., Sidaway, B., & Wilder, D. G. (1997). Motorcycle accident reconstruction under Daubert. *Journal of the National Academy of Forensic Engineering*, *14*, 1–18.

Most, S. B., Chun, M. M., Widders, D. M., & Zald, D. H. (2005a). Attentional rubbernecking: Cognitive control and personality in emotion-induced blindness. *Psychonomic Bulletin and Review*, *12*, 654–661.

Most, S. B., Scholl, B. J., Clifford, E. R., & Simons, D. J. (2005b). What you see is what you set: Sustained inattentional blindness and the capture of awareness. *Psychological Review*, *112*, 217–242.

Most, S. B., Simons, D. J., Scholl, B. J., Jimenez, R., Clifford, E., & Chabris, C. F. (2001). How not to be seen: The contribution of similarity and selective ignoring to sustained inattentional blindness. *Psychological Science*, *12*, 9–17.

Pratto, F., & John, O. P. (1991). Automatic vigilance: The attention-grabbing power of negative social information. *Journal of Personality and Social Psychology*, *61*(3), 380–391.

Rumar, K. (1990). The basic driver error: Late detection. *Ergonomics*, *33*, 1281–1290.

Simons, D. J., & Chabris, C. F. (1999). Gorillas in our midst: Sustained inattentional blindness for dynamic events. *Perception*, *28*, 1059–1074.

Strayer, D. L., Drews, F. A., & Johnston, W. A. (2003). Cell phone-induced failures of visual attention during simulated driving. *Journal of Experimental Psychology: Applied*, *9*, 23–32.

Theeuwes, J. (1992). Perceptual selectivity for color and form. *Perception and Psychophysics*, *51*, 599–606.

Trick, L. M., Enns, J. T., Mills, J., & Vavrik, J. (2004). Paying attention behind the wheel: A framework for studying the role of attention in driving. *Theoretical Issues in Ergonomics Science*, *5*, 385–424.

Yantis, S. (1993). Stimulus-driven attentional capture and attentional control settings. *Journal of Experimental Psychology: Human Perception and Performance*, *19*, 676–681.

Yantis, S., & Jonides, J. (1984). Abrupt visual onsets and selective attention: Evidence from visual search. *Journal of Experimental Psychology: Human Perception and Performance*, *10*, 601–621.

Manuscript received February 2006
Manuscript accepted July 2006
First published online December 2006