Driver's Multi-Attribute Task Battery Performance and Attentional Switch Cost Are Correlated with Speeding Behavior in Simulated Driving

Jie Zhang[1,2], Mengnuo Dai[1,2], and Feng Du[1,2(✉)]

[1] Key Laboratory of Behavioral Science, Institute of Psychology, Chinese Academy of Science, Beijing, People's Republic of China
duf@psych.ac.cn
[2] Chinese Academy of Sciences, Beijing, People's Republic of China

Abstract. Speeding is one of the leading factors for traffic casualties. It is important to identify underlying factors related with speeding behavior. Present study aimed to explore the relationship between speeding and two general cognitive abilities: multi-tasking and attention-switching abilities. We measured multi-tasking ability using Multi-Attribute Task Battery (MATB). The MATB performance includes hit rate and RT for monitoring task, track error for tracking task and control rate for resource management task. We used the attentional blink (AB) task to measure attention-switching ability. The AB refers to people's inability to detect a second target (T2) that follows within about five hundred milliseconds of an earlier target (T1) in the same location. The attentional switch cost, specifically AB magnitude, is the difference between the highest and lowest accuracy of T2 given correct report of T1 across five T1-T2 intervals. Finally, a driving simulator was used to measure drivers' speeding behavior. The results showed (1) max speeding ratio was significantly correlated with RT for monitoring task, control rate for resource management and AB magnitude; (2) regression analysis show that MATB performance and Attentional switch cost played the key role in predicting max speeding ratio while controlling the demographic variables, but only MATB performance had a significant effect on speeding duration. Thus MATB performance and attentional switch costs is important to predict speeding behavior in simulated driving.

Keywords: Attentional switch cost · Attentional blink · Multi-Attribute Task Battery · Simulated driving · Speeding

1 Introduction

Speeding is one of the leading factors for traffic casualties [1, 2]. In China, official statistics show that in 2013 there were 198394 recorded traffic crashes that resulted in 272263 casualties, of which nearly six percent were caused by speeding [3]. Speeding not only increases crash risks but also affects the severity of a crash [4]. A case-control study conducted by Kloeden et al. showed that the speed-crash rate relationship

D. Harris (Ed.): EPCE 2017, Part II, LNAI 10276, pp. 426–435, 2017.
DOI: 10.1007/978-3-319-58475-1_31

followed an exponential function on rural road with speed limits between 80 and 120 km/h [5]. Besides, Miltner and Salwender found fatality risk for belted front-seat passenger was about 30 times higher at 80 km/h than at 40 km/h [6]. Hence, it is important to identify underlying factors related with speeding behaviors.

Elandar et al. proposed a fourfold classification for variables that are related to crash risk: driving skills, driving styles, extrinsic abilities and traits [7]. The extrinsic abilities referred to those general perceptual-motor skills which play key roles in driving safety but extend beyond driving skills. Researchers found that ability to detect visual signals embedded in a complex background and ability to switch attention rapidly are related with better driving safety [8–11]. Present study aimed to examine the relationship between speeding and two general abilities: multi-tasking and attention-switching abilities.

Proper speed control requires drivers to simultaneously monitor car dashboard and road condition. In order to avoid collision and speed violation, drivers have to keep a safe distance from pedestrians, vehicles and any other potentially hazardous obstacles on the road while maintain their speed under limits. Therefore we proposed that multi-tasking ability is critical for speed control. We measured multi-tasking ability using Multi-Attribute Task Battery (MATB) which provides a set of simulated aviation tasks for laboratory studies [12]. The MATB requires operator to continuously track a randomly moving target (tracking task) while monitoring several warning lights and gauges (monitoring task), and managing fuel level in a simulated dynamic fuel system (resource management task). The three tasks simulate what aircrews regularly perform in their real-world task.

Attention-switching ability have been shown to be critical for driving safety because drivers need to constantly switch their attention between road situation and dashboard. In previous studies, the Visual Selective Attention Test (VSAT) was used to test the ability of switching attention spatially. The VSAT involves simultaneous presentation of two streams of numbers and letters at two sides of a screen. Participants are instructed to respond to certain stimuli in the two streams (e.g., all odd numbers at the left and even numbers at the right) according to the cue preceded to the beginning of the streams [13]. However, rapid response on multiple visual items (e.g., road condition, traffic signs, dashboard), which is essential to speed control, relies heavily on not only the spatial attention-switching ability but also the ability to process items rapidly, particularly the temporal attentional-switching ability. In this study, we tested whether temporal attentional-switching ability was a key factor for speed control by using attentional blink (AB) task. The AB refers to people's inability to detect or identify a second target (T2) that follows within about five hundred milliseconds of an earlier target (T1) in the same location [14–16]. Less switch cost in AB reflects better temporal attention-switching ability [17].

Driving simulators provide a controllable, cost-effective and safe testing environment for dangerous driving behavior [18]. Thus, a driving simulator was used to measure drivers' speeding behavior. MATB performance and attentional switch costs was expected to be correlated with speeding behavior in simulated driving task.

2 Method

2.1 Participants

37 participants (22 males and 15 females) took part in this experiment. They ranged in age from 22 to 50 years, with an average age of 29.9 years. All had normal or corrected-to-normal vision, valid driver's licenses and at least one year of driving experience.

2.2 Apparatus

The MATB and the AB task were implemented on a Core i7 desktop computer equipped with a 17-in. CRT monitor, a joystick and a standard keyboard. The monitor had a refresh rate of 85 Hz, a resolution of 1024 × 768 pixels and a viewing distance of 60 cm. The Sim-Trainer driving simulator, manufactured by Beijing Sunheart Inc., was used for the simulated driving task. The simulator consists of a complete cockpit and three high resolution displays, providing a 120° field of view.

2.3 MATB

We adopted the monitoring, tracking and resource management tasks from MATB to measure multi-tasking ability (Fig. 1).

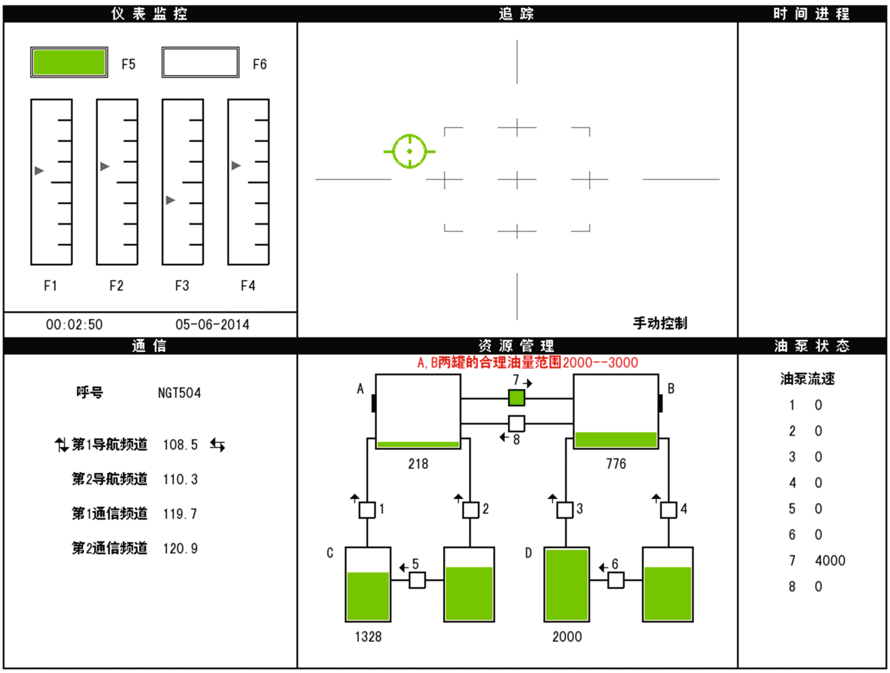

Fig. 1. Illustration of the interface in the Multi-Attribute Task Battery (MATB) (Color figure online)

The monitoring required attending to the four vertical gauges and the two warning lights (the upper left corner of display). In normal condition, the Green light (marked F5) was on, the Red light (marked F6) was off and the pointers of the gauges were within one unit above or below the centers. Participants were instructed to respond as soon as possible to the absence of the Green light, the presence of the Red light and the abnormally large deviation of the pointers by pressing corresponding keys on the joystick. The abnormal status of gauges and warning lights were randomly arranged and were counted as the abnormalities of monitoring of which the total number was 10 and 24 in two experimental blocks. The participant's hit rate and reaction time were calculated and recorded.

As the upper right corner of display shows, participant needed to keep tracking of a randomly-moving target in the tracking task. The root mean square (RMS) track errors, which was deviation from center of tracking target in pixel units, was recorded every 2.4 s. The tracking task were identical in two experimental blocks.

The resource management task required operator to maintain both tank A and B within the range of 2000–3000 units, which was indicated graphically by two black bars on the sides of the two tanks. This was done by turning on or off any of the eight pumps through pressing the corresponding keys on the joystick. All pumps were off at the onset of the task. Both tank A and B had 2100 units of fuel at the beginning and were depleted of fuel at the rate of 800 units per minute. The status of tank A and B were recorded every 14 ms. The parameters of the resource management task were identical in two experimental blocks. The control rate of tank A and tank B, the time percentage when target tank was in the desired range, were calculated.

2.4 Attentional Blink

In AB task, Participants were required to report the two targets embedded in a RSVP stream. After reporting the first target (T1) correctly, participants usually have difficulty in identifying the second target (T2). The impairment for reporting T2 is attentional blink. The attentional switch cost is the AB magnitude which is the difference between the highest and lowest accuracy of T2 given correct report of T1 across five T1-T2 intervals for each participant.

The RSVP stream was presented at the center of display. The background of the screen was black. Each trial began with the presentation of a fixation cross at the center of the screen. After 600 ms, the fixation cross was replaced by a rapidly-changing letter stream consisting of 20 upper-case white letters (1.3° in height). Letters were randomly chosen from the alphabet except the letter I. Each of the letters was presented for 40 ms and was followed by a 40 ms black screen interval, making the SOA 80 ms. T1, the first target, was a white digit randomly chosen between 2 and 9. It could appear in the 10th, 11th, or 12th frame in the stream. The letters kept changing at the same rate after T1 was presented. T2, the second target appeared in the 1st, 2nd, 3rd, 4th or 5th frames after T1. The T2 was a white letter chosen from letter A, B, X or Y. Participants were instructed to report both T1 and T2 as accurately as possible.

2.5 Simulated-Driving Task

We measured speeding behavior based on a simulated-driving task originated from our previous study [19]. Guided by auditory instructions, participants drove along a 3.6 km urban road on the driving simulator. Participants were instructed to limit their speed according to the speed signs. If they exceeded, the simulator would record the speeding duration and calculate the max speeding ratio as the max ratio of speed to speed limit.

2.6 Procedure

Participants came to lab twice at the interval of one week to avoid fatigue effect. Half participants first completed the AB and the MATB, and the other first completed the AB and the simulated-driving task.

The MATB began with 4 practice blocks: each block lasted 5 min, the first three blocks contained only one of the three sub-tasks without repetition and the last block contained both resource management and tracking task. Before the experimental blocks, participants were instructed that they would be performing the monitoring task, the tracking task and the resource management task simultaneously. There were 2 experimental blocks, each session lasted 5 min. The number of abnormalities in the monitoring task was randomly assigned to the two experimental blocks. The AB task consisted of 16 practice trails and 160 experimental trails. The simulated-driving task began with a 5 min practice session in which participants drove freely in a city to get accustomed the simulator. Before the experimental session, participants were instructed to limit their speed according to the speed signs and follow auditory instructions. The experimental session lasted 12–15 min.

3 Results

3.1 Task Performance

There was no practice effect in the MATB, therefore the data of the two experimental blocks of the MATB were combined. Furthermore, the control rate of the two target tanks in the resource management were merged because no significant difference between the target tanks was observed.

Table 1 listed the four MATB indices from the three sub-tasks, the AB magnitude, and two speeding indices from the simulated driving task. An additional correlation analysis between the MATB indices revealed strong positive correlations between the performance of the three sub-tasks: (1) the correlation between RT for monitoring task and track error for tracking task was significant ($r = .47$, $p < .01$), with slower anomaly detection corresponding to larger track deviation; (2) control rate for resource management was significantly correlated with tracking error, ($r = -.60$, $p < .01$), with poorer fuel management corresponding to larger track deviation; (3) control rate for resource management had a significant correlation with RT for monitoring task ($r = -.70$, $p < .01$), with poorer fuel management corresponding to slower anomaly detection.

Table 1. The MATB performance, AB magnitude and speeding indices (Mean ± SE)

MATB				AB	Simulated driving	
HR	RT (s)	TE (pixel)	CR	M	MSR	SD(s)
0.93 ± 0.01	3.69 ± 0.20	78.64 ± 3.74	0.87 ± 0.01	0.30 ± 0.02	0.29 ± 0.03	72.14 ± 6.61

Not. HR – Hit rate for monitoring; RT – RT for monitoring; TE – Track error for tracking; CR – Control rate for resource management; M – magnitude of AB; MSR – Max speeding ratio; SD – Speeding duration.

As shown in Fig. 2, the expected attentional blink was observed. The average T2 accuracy given correct reaction of T1 (T2/T1) reached its lowest at lag3, which was significantly lower than the average T2/T1 at lag1 ($t(36) = 2.31$, $p < .05$). Moreover, the AB magnitude, shown in Table 1, was calculated as the difference between the highest and lowest accuracy of T2/T1 across five T1-T2 intervals for each participant.

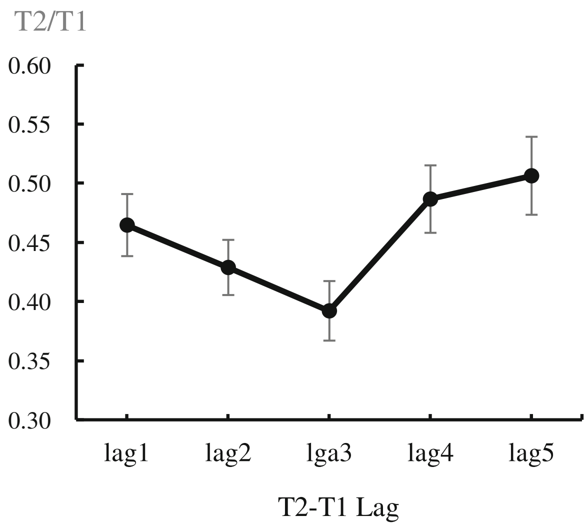

Fig. 2. The average T2/T1 as a function of T2-T1 lags

3.2 Correlation Analysis

The correlations between MATB performance, AB magnitude and speeding indices of the simulated driving task are shown in Table 2. The results showed, (1) monitoring RT was significantly correlated with max speeding ratio ($r = .32$, $p < .05$), with slower anomaly detection corresponding to higher max speeding ratio; (2) control rate of resource management had a significant negative correlation with max speeding ratio ($r = -.40$, $p < .05$), with worse resource management rate corresponding to higher max speeding ratio; (3) AB magnitude was significantly correlated with max speeding ratio ($r = .46$, $p < .01$), with larger attentional switch cost corresponding to higher max speeding ration. No significant correlation for speeding duration was found.

Table 2. The correlation between MATB performance, AB magnitude and speeding indices

	MATB				AB
	HR	RT	TE	CR	M
Max speeding ratio	−.25	.32*	−.15	−.40*	.46**
Speeding duration	−.20	.27	−.30	−.23	.21

Not. HR – Hit rate for monitoring; RT – RT for monitoring; TE – Track error for tracking; CR – Control rate for resource management; M – magnitude of AB; *p < .05, **p < .01.

3.3 Regression Analysis

We separately conducted three-step hierarchical regression analyses on the max speeding ratio and the speeding duration. Age and gender were entered at Step 1 to control potential demographic effect in the prediction of speeding behavior. The MATB performance was entered at Step 2 and finally the AB magnitude was entered at Step 3.

The results of the hierarchical regressions are shown in Table 3. The MATB performance accounted for 19% of the variance in max speeding ratio that is over and above the variance accounted for by age and gender, and this finding was a statistically significant increase. Moreover, in Step 3 the AB magnitude significantly increased R^2 by 14%. In Step 3 of predicting max speeding ratio, the standardized regression coefficients were significant for tracking error ($\beta = -.50$, $p < .01$), resource control rate ($\beta = -.54$, $p < .05$) and AB magnitude ($\beta = .39$, $p < .01$). The results indicated that drivers with smaller track deviation, poorer resource control rate and larger attentional switch cost have higher max speeding ratio; however the influence that the attentional switch cost has on max speeding ratio is relatively smaller.

Table 3. Predicting max speeding ratio and speeding duration

Step	Overall model		Predictors (β)						
	ΔR^2	ΔF	Age	Gender	HR	RT	TE	CR	M
Max speeding ratio									
1	.18	4.82*	−.24	−.45**					
2	.19	3.48*	−.12	−.25	−.05	−.03	−.52**	−.60*	
3	.14	9.71**	−.02	−.26	.01	.04	−.50**	−.54*	.39**
Speeding duration									
1	.02	1.30	−.13	−.26					
2	.26	4.00**	.03	−.03	−.18	.18	−.72**	−.39	
3	.00	1.14	.07	−.03	−.15	.19	−.70**	−.37	.16

Not. HR – Hit rate for monitoring; RT – RT for monitoring; TE – Track error for tracking; CR – Control rate for resource management; M – magnitude of AB; *p < .05, **p < .01.

In the regression model of speeding duration, the MATB performance accounted for 26% of the variance in speeding duration that is a significant increase over and above the variance accounted for by age and gender, while the entrance of the AB magnitude made no significant difference in the model. The standardized regression coefficient was significant only for track error ($\beta = -.70$, $p < .01$). The result indicated that when other variables are controlled, smaller track deviation predicts longer speeding duration.

4 Discussion and Conclusion

The purpose of this study was to examine the relationship between speeding behavior and two cognitive abilities including multi-tasking and attention-switching abilities. The results show that the MATB performance and AB magnitude can predict the speeding behavior in a simulated driving.

The present study found a significant positive correlation between the monitoring RT in MATB and the max speeding ratio of simulated driving. This finding suggests that the monitoring task overlaps with the speed control task. The monitoring task requires continuously monitoring the warning lights and abnormal situation of gauges scales [12], whereas speed control requires continuously monitoring the driving speed of a car and its trajectory. Moreover, the resource control rate of resource management task was significantly correlated with the max speeding ratio in simulated driving task. This finding indicates that the resource management task also shares common features with the speed control task. Both tasks require sustaining a high level of vigilance and choosing appropriate pumps/pedal strategically [12]. Finally, the correlation between the AB magnitude and the max speeding ratio was significant, which suggests that the temporal attention-switching ability plays a key role in speed control.

The hierarchical regression analyses showed that both MATB performance and attentional switch cost were important predictors for max speeding ratio, but only MATB performance had significant effect on speeding duration. In accordance with the correlation analysis, the hierarchical regression found the control rate for resource management and the AB magnitude were predictive of the max speeding ratio when demographic factors were controlled. This finding supports the notion that the control rate for resource management and the AB magnitude are critical factors in predicting speeding behavior in simulated driving. It is worth noting that the standard regression coefficients of tracking error were significantly negative in the regression models for both max speeding ratio and speeding duration, with better tracking performance associated with more speeding behavior. One possible explanation for current results is that drivers who had high tracking performance in multi-tasking might be more confident about their driving skill hence tended to maintain higher speed than what was required. One study showed that self-perception of skill and confidence were strong predictors for speeding behavior [20]. We propose that the relationship between tracking performance and speeding behavior need further investigation and should be understood in the context of multi-tasking.

One limitation of this study is the lack of validation of our measures of speeding behavior. As Godley et al. pointed out, participants generally drove faster in the instrumented car than the simulator, resulting in absolute validity not being established [21]. Further studies are needed to identify key cognitive factors for actual speeding behavior.

Taken together, this study suggests that MATB performance and attentional switch costs might be useful for predicting speeding behavior in simulated driving.

Acknowledgements. This study was supported by grants from the National Natural Science Foundation of China (31470982), and the scientific foundation of the Institute of Psychology, Chinese Academy of Sciences (Y4CX033008).

References

1. Liselotte, L.A., Glad, L.A., Beilinsson, L.: Observed vehicle speed and drivers' perceived speed of others. Appl. Psychol. **46**, 287–302 (1997). doi:10.1080/026999497378377
2. Elvik, R.: Speed limits, enforcement, and health consequences. Annu. Rev. Publ. Health **33**, 225–238 (2012). doi:10.1146/annurev-publhealth-031811-124634
3. China Road Traffic Accident Statistics Bureau (CRTASB): China Road Traffic Accidents Statistics. Traffic Administration Bureau of China State Security Ministry, Beijing, China (2013). (in Chinese)
4. Aarts, L., Schagen, I.V.: Driving speed and the risk of road crashes: a review. Accid. Anal. Prev. **38**, 215–224 (2006). doi:10.1016/j.aap.2005.07.004
5. Kloeden, C.N., Ponte, G., McLean, A.J.: Travelling speed and the risk of crash involvement on rural roads. Australian Transport Safety Board, Canberra, A.C.T. (2001)
6. Miltner, E., Salwender, H.-J.: Influencing factors on the injury severity of restrained front seat occupants in car-to-car head-on collisions. Accid. Anal. Prev. **27**, 143–150 (1995). doi:10.1016/0001-4575(94)00039-o
7. Elander, J., West, R., French, D.: Behavioral correlates of individual differences in road-traffic crash risk: an examination of methods and findings. Psychol. Bull. **113**, 279–294 (1993). doi:10.1037//0033-2909.113.2.279
8. Loo, R.: Individual differences and the perception of traffic signs. Hum. Factors **20**, 65–74 (1978). doi:10.1177/001872087802000109
9. Barrett, G.V., Thornton, C.L.: Relationship between perceptual style and driver reaction to an emergency situation. J. Appl. Psychol. **52**, 169–176 (1968). doi:10.1037/h0025658
10. Mihal, W.L., Barrett, G.V.: Individual differences in perceptual information processing and their relation to automobile accident involvement. J. Appl. Psychol. **61**, 229–233 (1976). doi:10.1037//0021-9010.61.2.229
11. Kahneman, D., Ben-Ishai, R., Lotan, M.: Relation of a test of attention to road accidents. J. Appl. Psychol. **58**, 113–115 (1973). doi:10.1037/h0035426
12. Comstock, J.R., Arnegard, R.J.: The multi-attribute task battery for human operator workload and strategic behavior research. National Aeronautics and Space Administration, Langley Research Center, Hampton, VA (1992)
13. Avolio, B.J., Alexander, R.A., Barrett, G.V., Sterns, H.L.: Designing a measure of visual selective attention to assess individual differences in information processing. Appl. Psychol. Meas. **5**, 29–42 (1981). doi:10.1177/014662168100500105
14. Chun, M.M., Potter, M.C.: A two-stage model for multiple target detection in rapid serial visual presentation. J. Exp. Psychol. Hum. **21**, 109–127 (1995). doi:10.1037//0096-1523.21.1.109

15. Raymond, J.E., Shapiro, K.L., Arnell, K.M.: Similarity determines the attentional blink. J. Exp. Psychol. Hum. **21**, 653–662 (1995). doi:10.1037//0096-1523.21.3.653
16. Shapiro, K.L., Caldwell, J., Sorensen, R.E.: Personal names and the attentional blink: a visual "cocktail party" effect. J. Exp. Psychol. Hum. **23**, 504–514 (1997). doi:10.1037//0096-1523.23.2.504
17. Green, C.S., Bavelier, D.: Action video game modifies visual selective attention. Nature **423**, 534–537 (2003). doi:10.1038/nature01647
18. Ivancic, K., Hesketh, B.: Learning from errors in a driving simulation: effects on driving skill and self-confidence. Ergonomics **43**, 1966–1984 (2000). doi:10.1080/00140130050201427
19. Yuan, Y., Du, F., Qu, W., Zhao, W., Zhang, K.: Identifying risky drivers with simulated driving. Traffic Inj. Prev. **17**, 44–50 (2015). doi:10.1080/15389588.2015.1033056
20. Adams-Guppy, J.R., Guppy, A.: Speeding in relation to perceptions of risk, utility and driving style by British company car drivers. Ergonomics **38**, 2525–2535 (1995). doi:10.1080/00140139508925284
21. Godley, S.T., Triggs, T.J., Fildes, B.N.: Driving simulator validation for speed research. Accid. Anal. Prev. **34**, 589–600 (2002). doi:10.1016/s0001-4575(01)00056-2