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Does Automatic Transmission Improve Driving Behavior in Older Drivers?

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Key Words
Automatic transmission · Manual transmission · Mobility · Older drivers · Speed adjustment · Traffic safety

Abstract
Background: Most older drivers continue to drive as they age. To maintain safe and independent transport, mobility is important for all individuals, but especially for older drivers. ***Objective:*** The objective of this study was to investigate whether automatic transmission, compared with manual transmission, may improve the driving behavior of older drivers. ***Method:*** In total, 31 older drivers (mean age 75.2 years) and 32 younger drivers – used as a control group (mean age 39.2 years) – were assessed twice on the same fixed route; once in a car with manual transmission and once in a car with automatic transmission. The cars were otherwise identical. The driving behavior was assessed with the Ryd On-Road Assessment driving protocol. Time to completion of left turns (right-hand side driving) and the impact of a distraction task were measured. ***Results:*** The older group had more driving errors than the younger group, in both the manual and the automatic transmission car. However, and contrary to the younger drivers, automatic transmission improved the older participants' driving behavior as demonstrated by safer speed adjustment in urban areas, greater maneuvering skills, safer lane position and driving in accordance with the speed regulations. ***Conclusion:*** Switching to automatic transmission may be recommended for older drivers as a means to maintain safe driving and thereby the quality of their transport mobility.

In developed countries, driving is seen as an important symbol of identity and independence [1]. The car enables mobility and access to essential services and social activities [2–4]. Consequently, most older drivers continue to drive as they age [5]. However, the complex interaction between sensory, cognitive and perceptual-motor processes required for safe driving are vulnerable due to the inherent changes that come with age [6].

Furthermore, as traffic density increases, the complexity of the driving task will increase [7]. Driving in complex traffic environments leads to high workload, especially in traffic situations that require interaction with other road users, for example at T-junctions [8]. In these interactive situations, older drivers have fewer cognitive processing

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resources than younger drivers [8]. In fact, older drivers crash more frequently in complex traffic environments, e.g. in intersections that involve turning, especially turning across the oncoming lane, and in complex traffic situations, e.g. when overtaking and merging [9–11].

The Michon model of driving behavior comprises a hierarchy of three levels [12]. The *strategic level* involves planning, timing and route, usually made before the actual driving. The *tactical level* involves activities and decisions while driving, e.g. adjusting speed and judgment of traffic situations. The *operational level* is the most basic and involves the actual perceptual-motor skills to control the vehicle, e.g. steering, braking and gear changing. There have been contradictory results about older drivers' performance regarding tactical and operational driving skills. While some claim younger drivers make more driving errors than their older counterparts [13], older drivers have been found to have more problems with operational driving skills, i.e. they drive more slowly and with poor lane positioning [14]. Another operational driving skill, gear changing, is often seen as an automatized task [12, 15]. For a novice driver, gear changing can be difficult and will not be automatized until it is overlearned after increasing practice [16]. However, for older drivers the execution of motor skills can become less automatized than previously [17], which could affect gear changing. In a previous study, inappropriate gear changes were found to be the fourth most common driving error in older drivers [18].

If older drivers fulfill the medical requirements for driving, the goal should be to maintain their transport mobility by driving safely for as long as possible [2–4]. Educational and training programs are available for older drivers to accomplish this. However, little is known about how other strategies can improve their driving behavior. For example, it remains unknown how transmission type affects driving behavior and whether or not a car with automatic transmission enhances safe driving. However, in a simulator study it was found that adolescent males with attention deficit/hyperactive disorders benefitted from using manual compared with automatic transmission regarding their attention skills [19]. In another simulator study, the components of braking time were analyzed, in order to assess the effects of, e.g. age and vehicle transmission type on braking time's two primary components, perception-reaction time and brake-movement time [20]. Whereas transmission type did not significantly affect either perception-reaction time or brake-movement time, perception-reaction time increased from 0.35 to 0.43 s with age. However, brake-movement time did not change with age. All these findings were based on low/median cost simulator driving, where the transmission type may be difficult to simulate [21–23]. In another study, physiological activity of drivers aged 25–35 years was measured, where it was found that use of automatic transmission may reduce stress reactions when driving in heavy city traffic [24]. To date, no studies comparing driving behavior in older drivers when driving manual versus automatic transmission cars have been published. Consequently, the aim of the present study was to investigate whether a car with automatic, compared with manual, transmission improves driving behavior in older drivers.

Methods

In order to achieve the objective of this study, a younger group of drivers was used as a control group. The study was approved by a local ethics committee in Gothenburg, Sweden. The data were collected in a driving assessment unit in Sweden from 2008–2009.

Participants

The participants were recruited via the Vehicle Registration Office, local senior organizations and local businesses. Invitation letters were sent to potential participants explaining the purpose of the study. In total, 63 drivers agreed to participate in the study. The two groups were the older driver group (n = 31, 42% women) and the younger driver group (n = 32, 44% women). The older group's mean age was 75.2 (SD = 4.9, ranging from 70 to 90 years) and the younger group's mean age was 39.2 (SD = 5.2, ranging from 27 to 48 years). The younger group did not comprise any novice drivers. All older participants currently owned and drove manual transmission cars. Twenty-eight participants in the younger group owned and drove manual transmission cars, while four participants owned automatic transmission cars. All participants had a valid driving license for manual transmission.

Procedures

The participants were assessed twice on the same fixed route; once in a car with manual transmission and once in a car with automatic transmission, in a randomly allocated balanced order. Every second participant in both groups started with the manual transmission car and continued immediately after with the automatic transmission car. The cars were identical except for the transmission type, i.e. the same car make (Volvo V50) and model year. Both cars were equipped with dual controls. Each driving test took approximately 35 min on public roads in a suburban district in right-hand side traffic. The route comprised a diversity of intersections, right and left turns, roundabouts and road signs. A driving assessor (a specially trained occupational therapist) assessed the drivers' behavior, e.g. how they followed instructions, maneuvered, managed lane positioning, obeyed traffic rules, interacted with other road users, and their attention. Their behavior was noted on a Ryd On-Road Assessment (ROA) driving protocol

1. Speed	2. Position	3. Attention	4. Indicator	5. Maneuvering	6. Instructions	7. Traffic rules
Too fast for the situation	To the right	To the right	No use of indicator	*Handling pedals*	Repeating needed	Give right of way
Too slow for the situation	*To the left*	To the left	Wrong direction	Steering	Reminding needed	Yield to traffic
Slow/late braking	Close to the vehicle in front	Ahead	Too late	*Changing gear*	Driving the wrong way	Obligation to stop
Braking without reason	Swaying between lanes	To the rear, including rear view mirror	Too early	Managing controls to the left		*Exceeding speed limit*
		Blind spot, to the right	Does not switch it off	Managing controls to the right		Rules regarding buses
		Blind spot, to the left		Reversing		Crossing a solid lane line

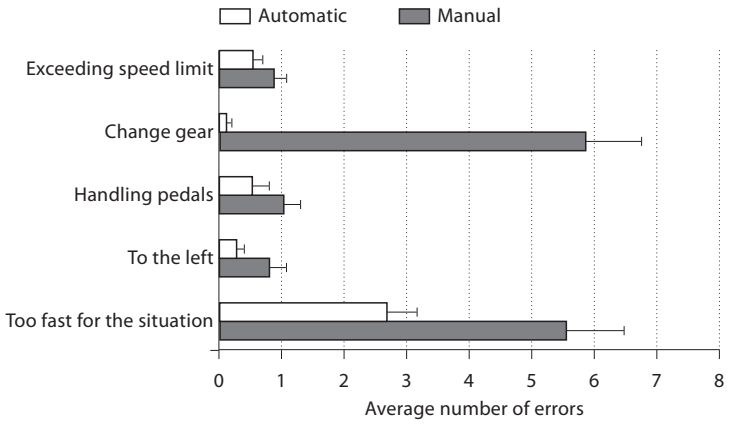

Fig. 1. The ROA protocol. Items indicated in italics were the ones in which the automatic transmission car had a significantly positive impact on the older group, which is further displayed in the bar chart in the lower part of the figure. Error bars display the positive SE of the mean.

scoring sheet, further presented below. A driving instructor had the safety responsibility (dual controls) and gave directions to follow throughout the route. The driving instructor sat in the front passenger seat and the driving assessor in the back seat to the right. A secondary task, aiming to distract the drivers, was given at pre-defined spots along the route. In addition to the assessment of their driving behaviors, their performance on this secondary task and the time it took to complete predefined left turns were measured. Details on these two measurements are further presented below. After the two driving tests, each participant completed a questionnaire about their experience of the differences between the two cars.

Driving Assessment Measurements

ROA Protocol

ROA was developed for a previous study and is utilized clinically at the driving assessment unit where the tests took place [18]. The scoring sheet comprises 34 specified items in seven categories, i.e. speed, position, attention, indicator, maneuvering, instructions, and traffic rules, as shown in figure 1. Errors made are graded on a 0–2 scale, where 0 implies normal driving behavior, 1 indicates minor error, while 2 indicates considerable risk-taking behavior. There is no upper limit to the scores.

Secondary Task

A secondary distraction task was predetermined at four roundabouts in each driving test. The participants received information about the nature of this secondary distraction task prior to the driving test. The instructions were to count out loud, starting from a specific number, e.g. 345, minus 3, as many times as possible during the roundabout. The distraction task had to be auditory, since we did not want to visually distract the drivers. This auditory method is a classic distraction task, built into valid and reliable test such as the TSST [25] among others. The number of correct numerical operations (x) was noted, as was the time per correct calculation (y). At the same time, a score based on the

Table 1. Driving measurements for the manual and automatic transmission car conditions, and for the older and the younger group, in addition to their 1st and 2nd drives, respectively

	Older group (n = 31)		Within-group tests and p values	Younger group (n = 32)		Within-group tests and p values	Between-groups test and p values
	mean	95% CI		mean	95% CI		
Driving errors (manual)	24.3	19.0–29.7	z = 4.86, p < 0.001*	6.2	4.8–7.5	z = 1.24, p = 0.21	z = 5.65, p < 0.001*
Driving errors (automatic)	10.6	8.1–13.1		5.4	3.9–6.9		t = 3.63, p = 0.001*
Driving errors (1st drive)	15.5	11.7–19.3	z = 1.10, p = 0.27	6.5	5.3–7.7	z = 2.49, p = 0.013*	z = 4.46, p < 0.001*
Driving errors (2nd drive)	19.4	13.7–25.1		5.1	3.5–6.7		z = 4.28, p < 0.001*
Left turns (manual), s	12.8	12.3–13.4	t = 3.17, p = 0.003*	11.9	11.5–12.2	t = 3.78, p = 0.001*	t = 3.03, p = 0.004*
Left turns (automatic), s	11.9	11.5–12.2		11.4	11.0–11.7		t = 2.14, p = 0.036*
Left turns (1st drive), s	12.5	12.2–12.8	t = 0.88, p = 0.38	11.7	11.3–12.0	t = 0.88, p = 0.39	t = 3.68, p = 0.001*
Left turns (2nd drive), s	12.2	11.5–12.8		11.5	11.2–11.9		t = 1.81, p = 0.075
Secondary task (manual)	4.1	3.5–4.8	t = 1.31, p = 0.20	4.5	3.7–5.3	t = 0.02, p = 0.98	t = 0.74, p = 0.046*
Secondary task (automatic)	4.6	3.5–4.9		4.5	3.8–5.2		t = 0.08, p = 0.94
Secondary task (1st drive)	3.8	3.1–4.5	t = 3.80, p = 0.001*	4.2	3.5–4.9	t = 6.19, p < 0.001*	t = 0.87, p = 0.39
Secondary task (2nd drive)	4.9	4.2–5.6		5.0	4.2–5.8		t = 0.31, p = 0.76

Asterisk indicates significant difference.

number of driving errors in the roundabout (z), using a 1–5 scale where higher was better, was noted. The scoring of (z) was done according to the following five score criteria: 5 = no errors; 4 = 1 error/need repeated instructions; 3 = 2 errors; 2 = 3 errors; 1 = 4 or more errors.

The outcome algorithm was:

$$\sum = \left[\frac{(2x)}{(y)}\right] \cdot (z).$$

The secondary task was thus both a distraction task and an outcome measurement.

Intersections – Left Turns

At three intersections, the instruction was to turn left after a complete stop from a feeder road into a trunk road with priority. From the driving instructor's word of command when free access was given to the trunk road, the drivers started to drive and the time (in seconds) was measured to a specific point (mean 68 m) on the trunk road.

Questionnaire

The questionnaire comprised 13 questions about the participant's experience and attitudes towards automatic transmission cars, e.g. 'If you were to buy a new car, what sort of transmission would you prefer?'

Statistical Analyses

Statistical analyses were performed using SPSS® (version 17.0). All variables were tested for normal distribution with the use of the Kolmogorov-Smirnov test. χ^2 tests, Wilcoxon signed-rank tests, Mann-Whitney U tests, and paired samples and independent samples Student's t tests were used with the α-level set at 0.05. Cohen's d was calculated where applicable.

Results

As shown in table 1, the older group demonstrated more driving errors, both in the car with manual transmission and in the automatic transmission car compared with the younger group, (Cohen's d = 0.94). The younger group performed the left turns in shorter time than the older group in the manual transmission car (Cohen's d = 0.78), as well as in the automatic transmission car (Cohen's d = 0.54). During the secondary task, the younger group performed slightly better (Cohen's d = 0.19) in the manual transmission car, whereas no differences were found between the two groups in the automatic transmission car.

In the older group, driving the automatic transmission car improved their driving behavior regarding the number of driving errors and during the turning left task (Cohen's d = 0.60), compared with when they drove the manual transmission car. However, the car with automatic transmission did not affect the driving behavior of the younger group, except for the turning left task (Cohen's d = 0.67).

Driving the exact same route twice implies that possible learning may have occurred for the drivers. In order to check for such effects, results from the first drive were compared with results from the second, as shown in table 1. Driving errors were found to be less frequent in younger drivers the second time they drove, regardless of transmission type. Furthermore, both groups of drivers managed the secondary task better the second time they

drove the route, regardless of type of transmission (Cohen's d = 0.68 for the older group and 1.10 for the younger group). As further shown in table 1, the younger group performed left turns quicker than the older group (Cohen's d = 0.93), but only in the first drive, regardless of transmission type.

The automatic transmission car had a positive impact on the driving behavior of the older group in five driving items within the ROA protocol. The two showing the largest impacts were Maneuvering – Change gear ($z = 4.63$, $p < 0.001$), indicating inappropriate gear usage, and Speed – Too fast for the situation ($z = 3.51$, $p < 0.001$), relating to problems with controlling the speed according to the situation. The other three items were Maneuvering – Handling pedals ($z = 2.83$, $p = 0.005$), Traffic rules – Exceeding speed limit ($z = 2.59$, $p = 0.010$), and Position – To the left ($z = 2.22$, $p = 0.027$).

When asked what type of transmission they would choose if they were to buy a new car, more than half of the older participants (58%) stated that they would buy a car with automatic transmission ($\chi^2 = 9.7$, $p = 0.008$). Thirteen percent would choose manual transmission and another 29% stated type of transmission was of less importance when buying a car. For the younger participants, 53% would choose automatic transmission, 19% manual transmission and another 28% stated the type was of less importance for them ($\chi^2 = 6.1$, $p = 0.050$).

Discussion

The present study found that the older participants' driving behavior improved when driving a car with automatic transmission. As a result of the automatic transmission, they displayed safer speed adjustments in urban areas, safer lane positioning, greater maneuvering skills and better attention to the speed regulations. Furthermore, their left turns improved by driving a car with automatic transmission. These results are consistent with other results, suggesting that manual gear changing is not an entirely automatized process [16], but in contrast to other findings [26]. Contrary to our findings in the older group, automatic transmission had only a minor effect on the driving behavior of the younger group. As a matter of fact, the only effect of automatic transmission was on their left turns.

The present study measured driving errors as an outcome variable. Driving errors are defined as '…unwanted results of involuntary actions whereas violations are conscious deviation from a rule or safe practice' [27]. Driving errors are thought to diminish with experience [28]. However, experienced drivers may actually display driving behaviors that can be dangerous [29]. Improved driving skills do not always indicate error-free driving behavior. Instead, there are different types of errors, with different kinds of implications [30]. Some driving errors do not disappear with experience and age. They may, actually, have become a habitual part of the driving behavior over many years for some older drivers [31]. In the present study, certain driving errors were more common than others in the older drivers group, e.g. speed adjustment and positioning, and these errors do predict crashes in older drivers [32, 33]. Furthermore, and similar to our findings, Reason et al. [31] found frequent driving errors regarding gear changing.

Several studies have reported that older drivers self-regulate their driving in certain driving situations, for example by driving slower or by reducing the time and distance driven [3, 5]. Moreover, older drivers seem to compensate for distractions by driving slower in complex traffic environments [34]. As shown in figure 1, a frequent driving error identified in the present study was that the older drivers drove faster than appropriate for the traffic situation. They might not have exceeded the speed limits, but their speed was deemed too high for the actual situation, e.g. when meeting vulnerable road users, crossing an intersection or driving through roundabouts. Driving requires simultaneous use of central and peripheral vision [35]. To determine speed, the main cue is the peripheral vision [28], which is important for safe driving [36]. Deterioration in visual functions may be a risk factor for crashes in older adults [36]. The inherent deterioration of the peripheral vision in humans while aging may actually be an explanation for our results. Correlations between decreased vision and speeding errors found in previous research support this suggestion [37].

The present study included a secondary task as a distraction. The term (driver) distraction is regularly used to refer to inattention or attending to something irrelevant. A definition of driver distraction is: '…when a driver is delayed in the recognition of information needed to safely accomplish the driving task because some event, activity, object, or person within or outside the vehicle compelled or tended to induce the driver's shifting attention away from the driving task' [38]. Many studies have focused on driver distraction, in particular on in-vehicle sources like mobile phones [34, 39]. Manual gear changing appeared to distract the older drivers in the present study. There was a significant difference between the older and the younger group on the second-

ary task, when driving the car with manual transmission. Similar age-related distraction effects have been found for both mobile phone usage and for radio tuning [40].

As an age group, our younger group was, in fact, 'middle aged'. This group constitutes the safest age cohorts of drivers [28]. Thus, it comes as no surprise that the automatic transmission car had no major effect on their driving behavior. Compared with the older drivers, they had fewer driving errors with both the manual transmission car and the automatic transmission car. Apparently, possible distraction from manual gear shifting was small enough not to be detected by the driver behavior measurements this study utilized.

A limitation of this study was the relatively small sample size. Moreover, there was no measurement of intrarater, interrater or test-retest reliability of the ROA protocol. In addition, the secondary task outcome algorithm, specifically designed for the present study, was based on the following two assumptions: (a) the ability to perform a correct calculation was weighted as more important than the time it took, and (b) the number of errors on the primary task (driving) had a larger impact on the outcome than both the number of correct answers (secondary task) and time per correct calculation (secondary task). However, this algorithm has not been used in previous studies and not been assessed from a content validity aspect. Considering the fact that the algorithm was used within all four conditions, viz. younger group manual transmission, younger group automatic transmission, older group manual transmission and older group automatic transmission, any measurement error due to the algorithm would most likely have affected all four conditions similarly. Furthermore, there was a risk that biased scoring may have occurred, since the assessor – for obvious reasons – could not be blinded to the participants' group belonging.

Conclusions

Automatic transmission improved the older participants' driving behavior by safer speed adjustments in urban areas, greater maneuvering skills, safer lane positioning and driving according to the existing speed limits. However, for younger drivers, automatic transmission had less effect on their driving behavior. Switching to automatic transmission may be recommended for older drivers as a means to maintain safe driving and thereby the quality of their transport mobility.

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References

1 Whitehead BJ, Howie L, Lovell RK: Older people's experience of driver licence cancellation: a phenomenological study. Austral Occup Ther J 2006;53:173–180.
2 Marottoli RA, de Leon CFM, Glass TA, Williams CS, Cooney LM Jr, Berkman LF: Consequences of driving cessation: decreased out-of-home activity levels. J Gerontol B Psychol Sci Soc Sci 2000;55:S334–S340.
3 Owsley C: Driving mobility, older adults and quality of life. Gerontechnology 2002;1:220–230.
4 Oxley J, Whelan M: It cannot be all about safety: the benefits of prolonged mobility. Traffic Inj Prev 2008;9:367–378.
5 Unsworth CA, Wells Y, Browning C, Thomas SA, Kendig H: To continue, modify or relinquish driving: findings from a longitudinal study of healthy ageing. Gerontology 2007;53:423–431.
6 Ball KK, Wadley VG, Edwards JD: Advances in technology used to assess and retrain older drivers. Gerontechnology 2002;1:251–261.
7 de Waard D: The Measurement of Driver's Mental Workload: The Traffic Research Centre. Haren, University of Groningen, 1996.
8 Verwey WB: On-line driver workload estimation. Effects of road situation and age on secondary task measures. Ergonomics 2000; 43:187–209.
9 Clarke DD, Forsyth R, Wright R: Behavioural factors in accidents at road junctions: the use of a genetic algorithm to extract descriptive rules from police case files. Accid Anal Prev 1998;30:223–234.
10 McGwin G Jr, Brown DB: Characteristics of traffic crashes among young, middle-aged, and older drivers. Accid Anal Prev 1999;31: 181–198.
11 Mayhew DR, Simpson HM, Ferguson SA: Collisions involving senior drivers: high-risk conditions and locations. Traffic Inj Prev 2006;7:117–124.
12 Michon JA: A Critical View of Driver Behaviour Models: What Do We Know, What Should We Do? New York, Plenum Press, 1985.
13 Carr D, Jackson TW, Madden DJ, Cohen HJ: The effect of age on driving skills. J Am Geriatr Soc 1992;40:567–573.
14 Perryman KM, Fitten LJ: Effects of normal aging on the performance of motor-vehicle operational skills. J Geriatr Psychiatry Neurol 1996;9:136–141.
15 Baddeley A: Working Memory: An Overview; Working Memory and Education. London, Elsevier, 2006.
16 Shinar D, Meir M, Ben-Shoham I: How automatic is manual gear shifting? Hum Factors 1998;40:647–654.
17 Brouwer WH, Ponds RWHM: Driving competence in older persons. Disabil Rehabil 1994;16:149–161.
18 Selander H, Lee HC, Johansson K, Falkmer T: Older drivers: on-road and off-road results. Accid Anal Prev 2011;43:1348–1354.

19 Cox DJ, Punja M, Powers K, Merkel RL, Burket R, Moore M, Thorndike F, Kovatchev B: Manual transmission enhances attention and driving performance of ADHD adolescent males: pilot study. J Atten Disord 2006; 10:212–216.
20 Warshawsky-Livne L, Shinar D: Effects of uncertainty, transmission type, driver age and gender on brake reaction and movement time. J Safe Res 2002;33:117–128.
21 Falkmer T: The trainer project – development of a new cost-effective Pan-European driver training methodology and how to evaluate it: SIMSEM 2002. Copenhagen, SIMSEM, 2002.
22 Falkmer T: Truck and bus driver training, can simulation contribute?; in Dorn L (ed): Driver Behaviour and Training. Aldershot, Ashgate Publishing, 2005, vol 2, pp 93–104.
23 Falkmer T, Gregersen NP: The trainer project – the evaluation of a new simulator-based driver training methodology; in Dorn L (ed): Driver Behaviour and Training. Aldershot, Ashgate Publishing, 2003, pp 407.
24 Zeier H: Concurrent physiological activity of driver and passenger when driving with and without automatic transmission in heavy city traffic. Ergonomics 1979;22:799–810.
25 Kirschbaum C, Pirke K, Hellhammer D: The 'trier social stress test' – a tool for investigating psychobiological stress responses in a laboratory setting. Neuropsychobiology 1993;28:76–81.
26 Ranney TA: Models of driving behavior: a review of their evolution. Accid Anal Prev 1994;26:733–750.
27 Ozkan T, Lajunen T, Chliaoutakis JE, Parker D, Summala H: Cross-cultural differences in driving skills: a comparison of six countries. Accid Anal Prev 2006;38:1011–1018.
28 Evans L: Traffic Safety, ed 1. Bloomfield Hills, Science Serving Society, 2004.
29 Summala H: Automatization, automation, and modeling of driver's behavior. Recherche Transports Sécurité 2000;66:35–45.
30 Stanton NA, Salmon PM: Human error taxonomies applied to driving: a generic driver error taxonomy and its implications for intelligent transport systems. Safe Sci 2009;47: 227–237.
31 Reason J, Manstead A, Stradling S, Baxter J, Campbell K: Errors and violations on the roads: a real distinction? Ergonomics 1990; 33:1315–1332.
32 Classen S, Shechtman O, Awadzi KD, Joo Y, Lanford DN: Traffic violations versus driving errors of older adults: informing clinical practice. Am J Occup Ther 2010;64:233–241.
33 Braitman KA, Kirley BB, Ferguson S, Chaudhary NK: Factors leading to older drivers' intersection crashes. Traffic Inj Prev 2007;8: 267–274.
34 Horberry T, Anderson J, Regan MA, Triggs TJ, Brown J: Driver distraction: the effects of concurrent in-vehicle tasks, road environment complexity and age on driving performance. Accid Anal Prev 2006;38:185–191.
35 Owsley C, McGwin G Jr: Vision and driving. Vision Res 2010;50:2348–2361.
36 Owsley C, McGwin G Jr: Vision impairment and driving. Surv Ophthalmol 1999;43:535–550.
37 Baldock MRJ, Berndt A, Mathias JL: The functional correlates of older drivers' on-road driving test errors. Topics Ger Rehab 2008;24:204–223.
38 Treat JR: A study of pre-crash factors involved in traffic accidents. Ann Arbor, University of Michigan, Highway Safety Research Institute, 1980.
39 Ma R, Kaber DB: Situation awareness and workload in driving while using adaptive cruise control and a cell phone. Int J Ind Ergon 2005;35:939–953.
40 McKnight AJ, McKnight AS: The effect of cellular phone use upon driver attention. Accid Anal Prev 1993;25:259–265.