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Muscle strength, postural balance, and cognition are associated with braking time during driving in older adults

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ABSTRACT

Background: Despite the well-known declines in driving performance with advancing age, there is little understanding of the specific factors that predict changes in key determinants such as braking time.

Objectives: The aims of this study were to determine the extent to which age, muscle strength, cognition and postural balance are associated with braking performance in middle-aged and older adults.

Methods: Male and female middle-aged adults (n = 62, age = 39.3 ± 7.1 years) and older adults (n = 102, age = 70.4 ± 5.8 years) were evaluated for braking performance, as well as in several motor and cognitive performance tasks. The motor evaluation included isokinetic ankle plantar flexor muscle strength, handgrip strength, and postural balance with and without a cognitive task. The cognitive assessment included the Mini Mental State Examination. Braking performance was measured using a driving simulator.

Results: Older adults exhibited 17% slower braking time, lower strength, and poorer performance in the postural balance ($p < 0.001$). For both older and middle-aged adults, significant correlates of braking time included performance in the postural balance tests, muscle strength, and cognitive function. However, after full model adjustment, only postural balance and cognitive function were significantly associated.

Conclusion: Muscle strength, postural balance, and cognition are associated with braking time, and may affect the safety of and driving performance in older adults. These findings may help to inform specific targeted interventions that could preserve driving performance during aging.

1. Introduction

In most developed countries, higher life expectancies lead to an increase in the number of older drivers (McCarthy, 2005; Lee et al., 2002; Man-Son-Hing et al., 2013). There are approximately 36.8 million licensed drivers in the United States, age 65 and older (Insurance Information Institute, 2016). In Brazil, there is an estimated 3.6 million drivers above 61 years (DENATRAN, 2009), and there is no upper age limit for permission to drive. Rather, authorization to renew a driver's license depends the current physical condition (i.e., mobility, vision, hearing and cognitive abilities) that are essential to respond to different traffic situations (McCarthy, 2005).

Public health interventions to support improved quality of life and healthy aging have contributed to the increased number of older adult drivers on the roads (McCarthy, 2005). In high-density population areas with large numbers of cars and other motor vehicles (e.g., motorcycles and bicycles), there are many simultaneous challenges that drivers encounter which significantly increase the risk of dangerous accidents. Therefore, the ability to execute precise and rapid braking is an important determinant for safe driving. Braking ability depends on a complex, coordinated set of tasks involving vision, cognition and mobility (Lee et al., 2002; Man-Son-Hing et al., 2013).

Braking time has been classified into two phases, including (1) perception and reaction time (i.e. the time it takes to stop accelerating and remove the foot from the accelerator pedal, which involves sensory perception and cognition), and (2) braking movement time (i.e., the time from first movement of foot off the accelerator, and the initial contact with the brake pedal, which involves sensory and motor skills) (McCarthy, 2005; Lee et al., 2002). In congested or high-speed driving

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areas, an appropriate braking time is critical, and the likelihood of rear-end collisions increases sharply, especially among older adult wherein the demand for rapid braking may exceed the performance capacity of the driver (McCarthy, 2005).

Previous studies suggest that the functional limitations associated with aging are related to progressive and gradual loss of physical and mental skills, and may interfere significantly with the ability to perform complex, coordinated tasks, such as driving, in which various simultaneous actions are required (Woolnough et al., 2013).

Significant age-related declines in neuromuscular function and musculoskeletal physiology may reduce muscle strength, and decrease coordination and motor control. Additionally, age-related degeneration of peripheral sensory receptors and nerves can affect the postural control of the lower limbs and force production, leading to poorer accuracy in driving performance (Woolnough et al., 2013; Lacherez et al., 2014).

There are few studies which have examined the extent to which these functional losses influence the ability to drive. The majority of this research has been conducted to examine visual and cognitive factors, and very few studies have considered motor performance (Lacherez et al., 2014).

Thus, better understanding how these skills impact the braking time would allow for improved evaluation of these drivers, as well as to develop specific interventions for augmenting driving safety in older adults. The main objective of this study was to evaluate the age-related differences in braking time, muscle strength, cognition and postural balance, and secondly, to identify key predictors of the braking time task.

2. Methods

This was a cross-sectional study, conducted at the Motion Study Laboratory of the Institute of Orthopedics and Traumatology, Hospital das Clínicas (HC), University of São Paulo School of Medicine (FMUSP).

2.1. Subjects

We evaluated 164 male and female volunteers divided in two groups: 1) 102 health older adults (70.4 ± 5.8 years) recruited at the Geriatric Outpatient Department of Hospital das Clinics, School of Medicine, University of São Paulo; and 2) 62 middle-aged health adults (39.8 ± 7.2 years). The inclusion criteria for both groups were: (1) having a valid driver's license for the past five years; (2) regular participation in driving for at least two days per week; (3) absence of vestibular, proprioceptive, auditory, neurological and/or mental impairment; (4) not using any medications that could alter the ability to drive; (5) no surgeries or injuries that could influence the mobility of lower and upper limbs and trunk; (6) no functional limitations in the range of joint movement of ankle, knee, hip or neck; and (7) visual acuity, measured by the Snellen optometric scale, of 20/40 or better (with or without glasses) as determined by a geriatric doctor; and (8) score in the Mini Mental State Examination (MMSE) within the normal limits for literate subjects (≥24 points). Furthermore, participants had to be able to perform the functional tests required by the physical examination and the Driving Simulator Test. This study was approved by the University research ethics committee and all subjects read and signed an informed consent document.

2.2. Procedures

Prior to data collection, all the subjects answered a questionnaire with personal information, socio-demographic data, driving history, and physical activity history. They were asked to identify their preferred leg for kicking a ball, which was then considered their dominant leg and the dominant upper limb based on their preferred arm to write. All subjects attended one session in the laboratory, and they were submitted to the following functional tests at the Movement Laboratory, which lasted approximately 1.5 h.

2.3. Measures

2.3.1. Cognitive

The Mini Mental State Examination (MMSE) consists of 11 items that assess domains of orientation, short-term memory, attention, and visual spatial skills, and was scored on a 30-point questionnaire. The test includes items to assess attention and calculation, recall, language, the ability to follow simple commands, and orientation. (Lourenço and Veras, 2006).

2.3.2. Motor

2.3.2.1. Plantar flexor muscle strength. Maximum dynamic strength of the plantar flexor muscles of the dominant and non-dominant lower limbs were measured using an isokinetic dynamometer (Biodex System 2, USA). Subjects were placed in a seated position, with support in the distal region of the thighs, and the soles of the feet resting on a rigid plate. The axis of motion of the ankle joint was aligned with the mechanical axis of the dynamometer, and the knee was kept at 30° of flexion. The subjects were strapped in by two belts across the chest and one across the pelvis, and with velcro strips on the distal part of the thigh, and area of the metatarsals in the dorsal region of the foot. Three submaximal attempts were made to familiarize the subject with the procedures, and then two sets of five maximal dynamic repetitions were conducted at 30°/s, with a one-minute interval between sets. Only the second set values were used for the data analyses, as previously described (Brech et al., 2011). Verbal encouragement was given throughout the tests to motivate the participants to develop the maximum torque during each repetition.

2.3.2.2. Hand grip strength. Maximal handgrip strength was determined with a Jamar® dynamometer, with the subject seated and with the arm parallel to the body, shoulder adduced, elbow flexed at 90°, and forearm and wrist in the neutral position. Three trials were performed on the dominant and non-dominant hands, with a one-minute interval between trials. The mean value was used for the analyses. (Caporrino et al., 1998).

2.3.2.3. Dynamic balance. Dynamic balance was evaluated with the Time Up and Go Test (TUGT), which is a test, comprised of mobility, transfers, gait, and is associated with strength, agility and postural balance (Schoene et al., 2013). The TUGT measures the time required for an individual to get up from a chair to a standing position, walk three meters in a normal walking speed, return to the chair, and sit back down (Schoene et al., 2013; Smith et al., 2016).

Additionally, subjects performed the TUGT with a dual task ("Time Up and Go Cognitive" – "TUGT cognitive"), which paired the motor activities with a verbal task, and in which the individuals were asked to speak name animals (Smith et al., 2016).

2.3.2.4. Driving Simulator Test. The virtual environment was generated by "Car-Simulator Trainer - Type F12PT" (Foerst GMBh), which simulates a vehicle equipped with steering wheel, speed dial, brake, accelerator and clutch pedals, gear stick, seat, seatbelt and headlights, and the driving route was visible on three 42″ LCD TV monitors. The subjects were instructed to adjust the seat, seatbelt and rear view mirror as he/she would ordinarily do upon sitting down in the driving simulator. To evaluate driving performance, a test of braking time was chosen, in which an obstacle appears suddenly during the journey, forcing the subject to brake as soon as possible, and braking time was measured by the simulator software. All subjects were familiarized with a virtual scenario consisting of a highway without traffic. Then, a true test was initiated with a similar condition. During the route, the word "stop" appeared randomly on the screen, and the subjects were required to bring the car to a halt as quickly as possible. This command was repeated five times at random. The dependent variables evaluated were (1) braking time (braking), (2) the number of kilometers driven, and (3) the total time to complete the entire route. The mean of the five braking times, and the mean speed were calculated by dividing the number of kilometers by the total time. Except for total distance traveled, which was the same for all subjects (3.33 km), the speed and consequently the test duration varies for each individual.

2.4. Statistical analysis

The normality and homogeneity of variances within the data were confirmed with the Komogorov-Smirnov and Levenes tests, respectively. The data are reported as means, standard deviations and percentage differences between older adults and middle-aged adults. One-way analysis of variance (ANOVA) was used to evaluate the effect of age (older adults vs. middle-aged adults) on braking time, dynamic balance task variables, plantar flexor muscle strength variables, the hand grip strength, and MMSE. Pearson's bivariate correlations were examined between braking time, age, dynamic balance task variables, plantar flexor muscle strength variables (PT/BW and Total Work), the hand grip strength, and MMSE. Simple linear regression models were conducted to determine the associations between motor and cognitive predictors (i.e., MMSE, and performance on TUGT cognitive) and braking time separately for each age group. Only variables with a significant correlation with braking time of $p \leq 0.05$ were included in a final multiple regression model. These variables were then ranked from lowest to highest *p* value. Specifically, the selected independent variables were added to a multiple linear regression model using a stepwise forward selection (i.e., the variables were added one by one, according to their position in the sequence). Only the independent variables with $p \leq 0.05$ remained in the final model. The data were analyzed in the program SPSS 20.0.

3. Results

Demographic characteristics and driving-related data of the subjects in this study are presented in Table 1, stratified by age category.

Braking time was significantly longer for older adults when compared to middle-aged adults [$F_{1.162} = 19.3$ $p \leq 0.001$]. Moreover, the older adults performed the simulation test at significantly slower speeds when compared to middle aged adults [$F_{1.162} = 25.4$ $p \leq 0.001$].

For both TUGTs (i.e., with [$F_{1.162} = 41.4$ $p \leq 0.001$] and without [$F_{1.162} = 31.3$ $p \leq 0.001$] cognitive tasks), older adults took significantly more time to complete the tasks. Older adults also performed worse on muscle strength testing for both Total Work [$F_{1.162} = 14.9$ $p \leq 0.001$] and PT/BW [$F_{1.162} = 22.9$ $p \leq 0.001$] during the plantar flexion. For hand grip strength, old adults were significantly weaker than middle-aged adults for both dominant and non-dominant hands [$F_{1.162} = 14.0$ $p \leq 0.001$]. There were no significant differences in MMSE between older and middle-age adults [$F_{1.162} = 3.3$ $p = 0.06$] (Table 2).

Pearson's correlation tests revealed that braking time was negatively correlated with both muscle strength (Total Work and PT/BW) and cognition (MMSE), and positively correlated with postural balance (TUGT with and without the dual tasks) (Table 3).

Table 2
Mean and standard deviation, percentage difference in motor and cognitive skills between older and middle-aged adults.

	Older adults M (SD)	Middle-aged adults M (SD)	Diff (%)
Braking time (s)	1.2(0.3)	1.0(0.2)*	17
Mean speed (km/h)	46.4(10.0)	54.5(10.0)*	14
TUGT (s)	7.6(2.1)	5.92(1.4)*	22
TUGT cognitive (s)	8.9(3.1)	6.11(1.6)*	31
MMSE	27.3(2.8)	28.2(1.8)*	3
Flexor plantar strength – right			
PT/BW (%)	73.6(30.6)	99.5(38.1)*	26
Total Work (J)	78.4(51.5)	113.0(61.5)*	30
Hand grip strength			
Dominant (kg/f)	33.3(10.2)	39.7(12.0)*	16
Non-dominant (kg/f)	30.5(9.0)	37.5(12.2)*	18

Legend: PT/BW - peak of torque adjusted by body weight; TUGT - Time Up Go Test; MMSE - Mini Mental State Examination; Diff - difference.
* $p \leq 0.05$

Among the older adults, linear regression analysis demonstrated that 7% ($P = 0.007$) of the variance in braking time was explained by TUGT; 14% ($P \leq 0.001$) was explained by MMSE and 11% ($P \leq 0.001$) was explained by cognitive TUGT. In middle-aged adults, 28% of the variance in braking time was explained by muscle strength (Total Work $P = 0.002$) and TUGT ($P = 0.006$); 8% ($P = 0.021$) was explained by MMSE, and 19% ($P \leq 0.001$) was explained by cognitive TUGT (Table 4).

4. Discussion

The primary findings of this study were that age-related changes related to physical function and cognition can significantly interfere with the ability to perform critical driving tasks. By comparing older adults with middle-aged adults, we were able to determine which factors can interfere with braking time. Such information can be used to inform future, targeted interventions to improve physical and cognitive function, and thus reduce the risk of automobile accidents.

We found no differences in MMSE scores between middle-aged and older adults. However, for both middle-aged and older adults, MMSE was significantly associated with braking performance, such that better MMSE scores were associated with faster braking time. Odenheimer et al. (1994) demonstrated a high correlation between MMSE and driving performance ($r = 0.72$, $p < 0.01$); however, their sample also included participants referred from a dementia clinic.

Older adults exhibited longer braking times than the middle-aged adults. These results are similar to those of Martin et al. (2010) who reported that the poorer braking ability was due to increased braking time, with an increase in the distance traveled before the vehicle came to a halt. Similarly, Anstey and Wood (2011) demonstrated that older adult drivers were less capable of accurately stopping at the stop signal and drove at a slower speed.

In our study, older adults tended to drive significantly slower than middle-aged adults, which might be attributable to self-perception of having a visual, cognitive and/or motor disability. During challenging

Table 1
Demographic and self-reported driving characteristics.

	Older adults			Middle-aged adults		
	Women N = 51 M (SD)	Men N = 51 M (SD)	Total N = 102 M (SD)	Women N = 31 M (SD)	Adults Men N = 31 M (SD)	Total N = 62 M (SD)
Age (years)	68.0(4.5)	72.5(5.7)	70.4(5.8)	41.3(6.9)	38.0(6.9)	39.3(7.1)
Years licensed	38.8(7.7)	47.0(8.9)	42.8(9.2)	18.0(6.4)	17.8(7.3)	17.9(6.6)
Years education	12.5(2.8)	12.5(3.3)	12.6(3.0)	16.1(3.3)	15.3(1.5)	15.7(2.5)
Driving frequency km/week	97.5(92.1)	148.2(150.0)	123.3(123.4)	258.1(180.3)	236.7(216.0)	245.9(199.8)

Legend: M - mean; SD - standard deviation.

Table 3
Pearson correlation between braking time with motor and cognitive domains.

Domains		Braking time(s)	
		Older adults r(p)	Middle-aged adults r(p)
Motor	TUGT(s)	0.265(<0.01)	0.372(<0.01)
Strength right plantar flexor	PT/BW (%)	−0.223(0.02)	−0.402(<0.01)
	Total Work (J)	−0.213(0.03)	−0.421(<0.01)
Hand grip	Dominant limb (kg/f)	−0.174(0.08)	−0.416(<0.01)
	No dominant limb (kg/f)	−0.125(0.21)	−0.038(0.77)
Cognitive	MMSE	−0.374(<0.01)	−0.294(0.02)
Dual task	TUGT cognitive(s)	0.339(<0.01)	0.439(<0.01)

Legend: PT/BW - peak of torque adjusted by body weight; TUGT - Time Up Go Test; MMSE - Mini Mental State Examination.

situations, older adult drivers tend to slow down, and have more difficulty in controlling the car, which leads to a more defensive driving strategy to anticipate dangerous events (Woolnough et al., 2013; O'Connor et al., 2012). Adding to this, Bélanger et al. (2010) also demonstrated that older adults used brakes more frequently, and changed lanes less while driving.

Older adults performed significantly slower TUGT and cognitive TUGT as compared to middle-aged adults. Moreover, there was a positive association with cognitive TUGT performance and braking time for both groups (i.e., slower TUGT performance was associated with slower braking time). This is supportive of other work, which has linked the risk of automobile accidents with poor control postural and risk of falls (Wood et al., 2013). Moreover, Gaspar et al. (2013) demonstrated that individuals with poor performance in the Physiological Profile Assessment also had longer braking times in situations of danger.

The correlation between cognitive TUGT and braking time was greater than that between TUGT and braking time in both groups. Previous research (Schoene et al., 2013; Gaspar et al., 2013) has shown that differences in performing dual tasks are associated with a decrease in executive control, which is important for selection, planning, and coordinating of the processing of tasks, and is essential to perceive and execute an accurate and rapid braking motion.

Driving ability declines with age, but chronological age cannot be used as a sole factor to determine driving competency, as aging is a heterogeneous process that affects individuals differently. Muscle strength and postural balance, as well as cognition, are important predictors of braking time. These findings highlight important factors that can influence driver safety, and may assist in the development of interventions that could improve the task of driving for a longer period of time. In accordance with Lacherez et al. (2014), targeted exercises may be a possible intervention for augmenting driving safety among aging adults, as

Table 4
Stepwise multiple regressions for functional domains as predictors of braking time.

Braking time (s)	B	Standard Error	P-Value	Adjusted r^2
Older adults				
Motor				
TUGT (s)	0.037	0.01	0.007	0.07
Cognitive				
MMSE	−0.374	0.01	≤0.001	0.14
Dual task				
TUGT cognitive (s)	0.033	0.01	≤0.001	0.11
Middle-aged adults				
Motor				
Total Work (J)	0.002	0.001	0.002	0.28
TUGT (s)	0.064	0.02	0.006	
Cognitive				
MMSE	−0.044	0.02	0.021	0.08
Dual task				
TUGT cognitive(s)	0.076	0.02	≤0.001	0.19

Legend: TUGT - Time Up Go Test; MMSE - Mini Mental State Examination; β - beta value.

there is preliminary evidence that physical activity can improve older peoples' driving confidence. There is also considerable evidence that exercise interventions can improve strength, balance, and functional task performance (Peterson et al., 2010; Lacherez et al., 2014).

Hand grip strength testing is recommended as a test of fragility by American Medical Association (AMA guide) (Bélanger et al., 2010). In our study, weaker handgrip strength in dominant side was associated with longer braking times in middle-aged adults, but not in the older adult. However, we showed that older adults had significantly weaker hand grip strength compared to middle-aged adults in both the dominant and non-dominant hands. Given the feasibility of this test for clinical or community settings, future work is needed to determine thresholds of grip strength (i.e., weakness) for detection of neuromotor deficits such as slow braking.

The older adults had significantly lower plantar flexor strength of the ankle of PT/BW and Total Work, compared to middle-aged adults. Moreover, lower strength during the plantar flexor was associated with poorer performance in braking time in both groups, which is supportive of other studies (Lacherez et al., 2014; Caporrino et al., 1998). Although the measurement of muscle strength is a feature of all studies related for motor evaluation, this makes part of the Assessment of Driving Related Skills (ADReS) (Bélanger et al., 2013). For the present study, an isokinetic dynamometer of the ankle planter flexor muscles was chosen due to the specificity of movement, and by presenting a better relationship with the dynamic task of braking.

Based on the multiple linear regression models, the present analyses revealed that, among older adults, the TUGT was the only predictor, explaining 7% of the variance in braking time. In middle-aged adults, plantar flexor strength (Total Work) and TUGT, were the best predictors of braking time in the stepwise models. Weakness of the triceps surae muscle could affect the breaking time, because the movement takes the foot off the accelerator and immediate contact with the brake requires muscular power, agility/mobility and sensory perception and cognition. These data support the results of Wood et al. (2013) that showed the drivers' performance, in a real situation (driving a car on a highway), was linked to the quadriceps strength test and sway path length. Likewise, Lacherez et al. (2014) showed that proprioception, quadriceps strength and postural sway were present.

In the cognitive domain, although the MMSE was used as an inclusion criterion, the test explained 14% of the variance in braking time in older adult, and 8% of the variance in middle-aged adults, with lower scores being associated with poorer driving performance. A majority of studies have used MMSE as an inclusion criterion; however, only few of them considered it a cognitive variable for statistical analysis. Wood et al. (2013) reported that the predictive value is small, and that the maximum score of 30 points limits the application of the test in the investigation of the influence of cognitive function on driving skill. Better cognitive tests currently exist, which are more sensitive and specific to evaluate drivers in relation to attention, speed of processing, and executive function, etc. (Woolnough et al., 2013), but they are also more complex and less feasible as a population screening tool. The MMSE is easy to administer, and may indicate a need for follow-up examination if the score is too low.

In the dual task domain, multiple cognitive and motor tasks appeared to be more important. The cognitive TUGT explained 11% of the performance in the braking time in older adult and 19% in adults, which may be due to the direct association with executive function. According to Asimakopulos et al. (2012), executive function is an integral component in determining capacity to drive, and it is a construct proposed to explain higher order regulatory cognitive processes. Poor performance in control executive is a predictor of traffic accidents, and is often included in models to evaluate the risk of accidents among the older adult (Smith et al., 2013; Asimakopulos et al., 2012).

The independent predictors of braking time in older adults were performance in the postural balance with and without cognitive task, and scores in the MMSE. In middle-aged adults, predictors also included performance in the postural balance with and without cognitive task, muscle strength of the plantar flexors of the ankle and scores in the MMSE.

This study is not without limitations. First, the ability to drive safely is a multifactorial phenomenon with many interrelated predictive variables. Thus, because the focus of this research was motor evaluation, it is quite possible that other important factors such as cognition and vision are equally important for safe driving. Secondly, driving stimulators do not necessarily reflect real life driving scenarios; and yet, they have proven to be a useful tool for evaluating the competencies required for driving. These devices create driving situations that would be difficult to safely reproduce in the real environment, enabling an individual's driving skills to be evaluated in a safe and cost-effective way (Lee et al., 2002; Classen et al., 2006). Lastly, we included only healthy middle-aged and older adults, and therefore our findings are not generalizable to other populations, particularly with multiple chronic conditions that could influence the explanatory variables.

In conclusion, muscle strength, postural balance, and cognition are associated with braking time, and may affect the driving performance in older adults. These findings may help to develop specific interventions than can preserve driving performance during aging.

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References

Anstey, K.J., Wood, J., 2011. Chronological age and age-related cognitive deficits are associated with an increase in multiple types of driving errors in late life. Neuropsychology 25 (5), 613–621. http://dx.doi.org/10.1037/a0023835.

Asimakopulos, J., Boychuck, Z., Sondergaard, D., Poulin, V., Ménard, I., Korner-Bitensky, N., 2012. Assessing executive function in relation to fitness to drive: a review of tools and their ability to predict safe driving. Aust. Occup. Ther. J. 59 (6), 402–427. http://dx.doi.org/10.1111/j.1440-1630.2011.00963.x (Epub 2011 Nov 13).

Bélanger, A., Gagnon, S., Yamin, S., 2010. Capturing the serial nature of older drivers' responses towards challenging events: a simulation study. Accid. Anal. Prev. 42, 809–817.

Brech, G.C., Ciolac, E.G., Secchi, L.L.B., et al., 2011. The effects of motor learning on clinical isokinetic performance of postmenopausal women. Maturitas 70 (4), 379–382.

Caporrino, F.A., Faloppa, F., Santos, J.B.G., et al., 1998. Estudo populacional da força de preensão palmar com dinamômetro Jamar. Rev. Bras. Ortop. 33, 150–154.

Classen, S., Shechtman, O., Stephens, B., et al., 2006. The impact of intersection design on simulated driving performance of young and senior adults preliminary results. Top Geriatr. Rehabil. 22 (1), 27–35.

DENATRAN. O Trânsito nosso de cada dia. 2009. (Available:http://www.denatran.gov.br/download/SNT_o_transito_nosso_de_cada_dia.doc. Accessed may 06, 2015).

Gaspar, J.G., Neider, M.B., Kramer, A.F., 2013. Falls risk and simulated driving performance in older adults. J. Aging Res. 2013, 356948. http://dx.doi.org/10.1155/2013/356948.

Insurance Information Institute, 2016. Available: http://www.iii.org/issue-update/older-drivers. Acessed Jan. 21, 2016.

Lacherez, P., Wood, J.M., Anstey, K.J., et al., 2014. Sensorimotor and postural control factors associated with driving safety in a community-dwelling older driver population. J. Gerontol. A Biol. Med. Sci. 69 (2), 240–244. http://dx.doi.org/10.1093/gerona/glt173 (Epub 2013 Oct 29).

Lee, H.C., Drake, V., Cameron, D., 2002. Identification of appropriate assessment criteria to measure older adults' driving performance in simulated driving. Aust. Occup. Ther. J. 49 (3), 138–145.

Lourenço, R.A., Veras, R.P., 2006. Mini-Exame do Estado Mental: características psicométricas em idosos ambulatoriais. Rev. Saude Publica 40 (4), 712–719.

Man-Son-Hing, M., Bédard, M., et al., Dec 2013. Protocol for Candrive II/Ozcandrive, a multicentre prospective older driver cohort study. Accid. Anal. Prev. 61, 245–252. http://dx.doi.org/10.1016/j.aap.2013.02.009 (Epub 2013 Mar 7).

Martin, L., Audet, T., Corriveau, H., et al., 2010. Comparison between younger and older drivers of the effect of obstacle direction on the minimum obstacle distance to brake and avoid a motor vehicle accident. Accid Anal Prev. 42, 1144–1150.

McCarthy, D.P., 2005. Approaches to improving Elders' safe driving abilities. Phys. Occup. Ther. Geriatr. 23, 25–42.

O'Connor, M.L., Edwards, J.D., Small, B.J., et al., Jul 2012. Patterns of level and change in selfreported driving behaviors among older adults: who self-regulates? J. Gerontol. B Psychol. Sci. Soc. Sci. 67 (4), 437–446. http://dx.doi.org/10.1093/geronb/gbr122.

Odenheimer, G.L., Beaudet, M., Jette, A.M., et al., 1994. Performance-based driving evaluation of the elderly driver: safety, reliability, and validity. J. Gerontol. 49 (4), M153–M159.

Peterson, M.D., Rhea, M.R., Sen, A., Gordon, P.M., Jul 2010. Resistance exercise for muscular strength in older adults: a meta-analysis. Ageing Res. Rev. 9 (3), 226–237. http://dx.doi.org/10.1016/j.arr.2010.03.004 (Epub 2010 Apr 10).

Schoene, D., Wu, S.M., Mikolaizak, A.S., et al., 2013. Discriminative ability and predictive validity of the timed up and go test in identifying older people who fall: systematic review and meta-analysis. J. Am. Geriatr. Soc. 61 (2), 202–208. http://dx.doi.org/10.1111/jgs.12106 (Epub 2013 Jan 25).

Smith, A., Marshall, S., Porter, M., et al., 2013. Stability of physical assessment of older drivers over 1 year. Accid. Anal. Prev. 61, 261–266. http://dx.doi.org/10.1016/j.aap.2013.02.007.

Smith, E., Walsh, L., Doyle, J., Greene, B., Blake, C., Jan 2016. The reliability of the quantitative timed up and go test (QTUG) measured over five consecutive days under single and dual-task conditions in community dwelling older adults. Gait Posture 43, 239–244. http://dx.doi.org/10.1016/j.gaitpost.2015.10.004 (Epub 2015 Oct 19).

Wood, J.M., Horswill, M.S., Lacherez, P.F., et al., Jan 2013. Evaluation of screening tests for predicting older driver performance and safety assessed by an on-road test. Accid. Anal. Prev. 50, 1161–1168. http://dx.doi.org/10.1016/j.aap.2012.09.009 (Epub 2012 Oct 22).

Woolnough, A., Salim, D., Marshall, S.C., et al., 2013. Determining the validity of the AMA guide: a historical cohort analysis of the assessment of driving related skills and crash rate among older drivers. Accid. Anal. Prev. 61, 311–316. http://dx.doi.org/10.1016/j.aap.2013.03.020 (Epub 2013 Mar 26).