Visual load and variability of muscle activation: Effects on reactive driving of older adults

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ABSTRACT

Background: The functional significance of the increase in motor output variability with increased visual information processing in older adults remains unclear. Here, we test the hypothesis that increased visual information processing increases muscle activation variability in older adults and impairs their ability to react as fast and as precisely as young adults during a simulated reactive driving task.

Methods: Fourteen young and sixteen older adults performed a reactive driving simulation task that required responding to unexpected brake lights of the car ahead during a simple reaction time task (low visual information processing condition) and a choice reaction time task with "no go" trials condition (high visual information processing condition). We quantified the following: 1) reactive driving performance – combination of premotor response time, motor response time, and brake force error; 2) motor output variability – brake impulse variability; 3) muscle activation variability – variability in the tibialis anterior (TA) muscle activity.

Results: The increase in information processing exacerbated the impaired reactive driving performance in older adults. The best predictor of this impairment was the increase in brake force error. The impaired reactive driving performance was related to brake impulse variability and variability in the TA activity.

Conclusions: This study provides novel evidence that increased information processing increases muscle activation variability in older adults with detrimental consequences to their ability to perform a simulated reactive driving task.

1. Introduction

The functional significance of increased motor output variability in older adults is decreased movement accuracy (Harris & Wolpert, 1998), impaired motor learning (Wolpert, Ghahramani, & Flanagan, 2001), and increased risk for falling (Lajoie & Gallagher, 2004). Recently, we demonstrated that increased motor output variability also impairs the ability of older adults to respond equally well to young adults during a simulated reactive driving task (Lodha, Moon, Kim, Onushko, & Christou, 2016). Driving requires constant visual information processing (Perryman & Fitten, 1996) and there is strong evidence that increased visual information (e.g. magnification of visual feedback) amplifies motor output variability in older adults (Baweja, Kwon, & Christou, 2012; Fox et al., 2013; Kennedy & Christou, 2011; Sosnoff & Newell, 2006; Tracy, Dinenno, Jorgensen, & Welsh, 2007; S. J. Welsh,

Dinenno, & Tracy, 2007; T. N. Welsh, Higgins, & Elliott, 2007). In this study, we sought to determine whether increasing the visual information processing in older adults results in greater muscle activation variability and consequently exacerbates reactive performance during a simulated driving task.

Driving is a complex skill that requires the integration of sensory inputs, cognitive processing, and motor execution (Christou et al., 2017; Perryman & Fitten, 1996). Like many other skills, the driving ability deteriorates with age (Ball & Rebok, 1994). Poorer driving performance in older adults is associated with attentional deficits (Ball, Owsley, Sloane, Roenker, & Bruni, 1993; Owsley et al., 1998; Owsley, Sloane, Ball, Roenker, & Bruni, 1991), impaired perceptual and visuo-spatial ability (McKnight & McKnight, 1999), and slower reaction time (McKnight & McKnight, 1999). Recently, we used a simulated driving task to examine the ability of older adults to react with precise braking force in response to an unexpected visual stimulus (Lodha et al., 2016). This task simulated car following, an important component of daily driving. We found that older adults had impaired reactive performance compared with young adults, and this impairment was strongly related to their greater motor output variability (Lodha et al., 2016). However, this finding was based on one visual stimulus/response scenario (simple reaction time task).

Driving is more complex and often necessitates the integration of visual information from various sources. An increase in visual information processing could exacerbate motor output variability and consequently the reactive driving impairments in older adults. This hypothesis is supported by the following findings: 1) Older adults have higher car accident rates during visually more complex driving situations, such as crossing an intersection with traffic (McGwin & Brown, 1999; Preusser, Williams, Ferguson, Ulmer, & Weinstein, 1998; Ryan, Legge, & Rosman, 1998). 2) Motor output variability increases in older adults with magnification of visual feedback, an experimental condition that increases visual information processing (Baweja et al., 2012; Fox et al., 2013; Kennedy & Christou, 2011; Sosnoff & Newell, 2006; Tracy et al., 2007; S. J. Welsh et al., 2007; T. N. Welsh et al., 2007). One possible mechanism is that increased visual information processing increases muscle activation variability. Support to this general hypothesis is provided by the findings of Welsh et al. (2007), who have shown that older adults have increased motor unit discharge rate variability with increased visual feedback (S. J. Welsh et al., 2007). Thus, it is possible that increasing the processing of visual information increases the muscle activation variability in older adults with functional consequences.

Here, we test the hypothesis that increased visual information processing increases the variability of muscle activation in older adults and impairs their ability to react as fast and as precisely as young adults during a simulated driving task. We used the same simulated reactive driving task as before (Lodha et al., 2016) and manipulated the visual information processing by increasing the number of the visual stimuli and by adding "No go" trials.

2. Methods

2.1. Participants

Fourteen young adults (24.6 ± 3.1 years, 8 females) and 16 older adults (72.4 ± 5.6 years, 7 females) volunteered to participate in this study. All participants were current drivers, with normal or corrected vision, and reported being healthy without any known orthopedic or neurological problems. The Institutional Review Board at the University of Florida approved all the procedures for this study, and participants signed a written informed consent before participating in the study.

2.2. Experimental approach

Participants attended a single two-hour experimental session. Each participant began with familiarization of the experimental procedures. The familiarization period included a verbal explanation of the reactive driving task and 10 practice trials. After the familiarization period, each participant performed reactive driving tasks involving two different visual load conditions (low and high loads). The order of visual load conditions was counterbalanced. Each trial lasted ~25 s, which included up to ~15 s of the actual task and 10 s of performance feedback. Participants received 10 s of rest between trials, one minute of rest between blocks (11 trials/block), and three minutes of rest between visual load conditions. Each participant performed a total of 100 trials.

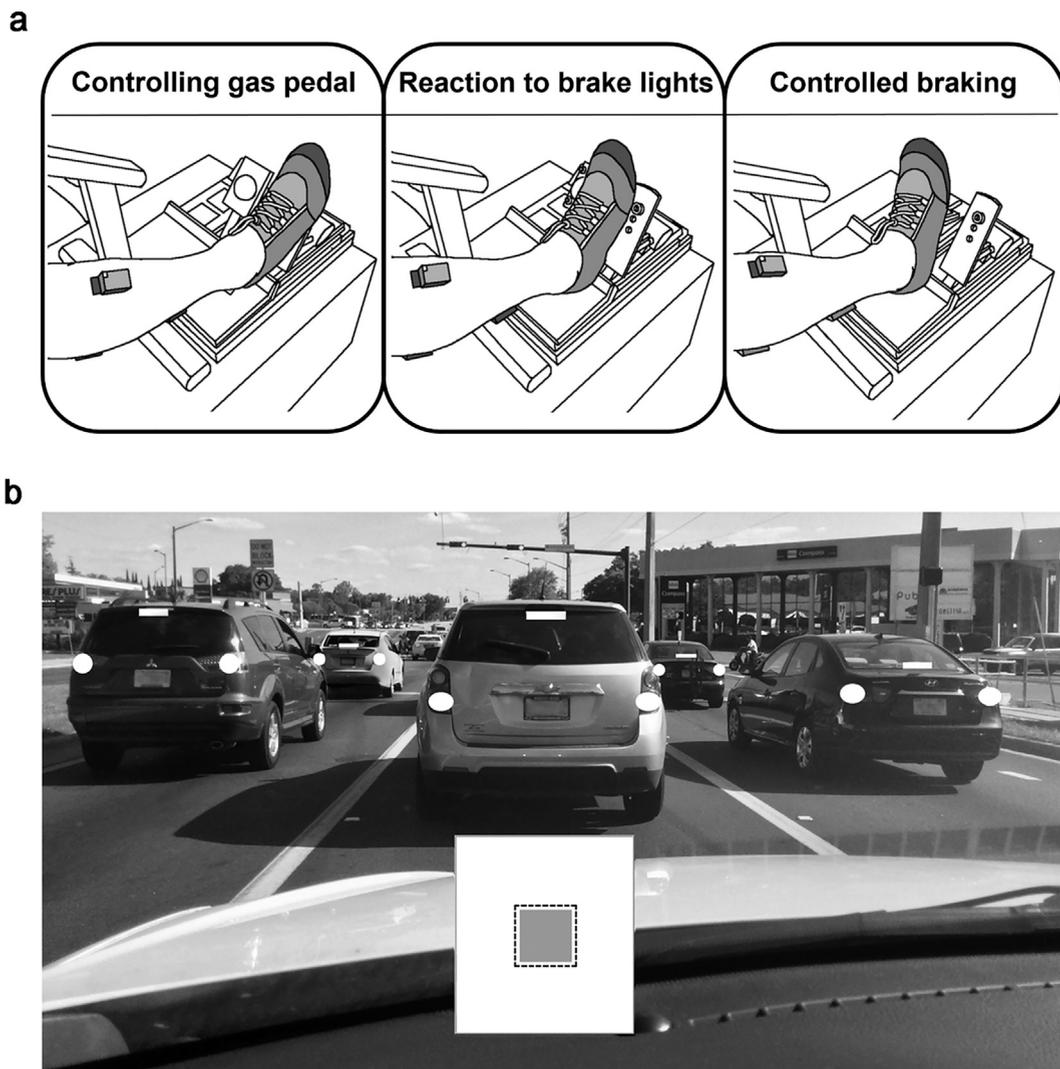### 2.3. Reactive driving task

2.3.1. Experimental setup

Participants seated comfortably in a driving seat and faced a 32-inch monitor (Sync Master™ 320MP-2, Samsung Electronics America, NJ, USA, resolution: 1920 × 1080, refresh rate: 60p Hz) that provided visual feedback of (1) ankle movements on the gas pedal and (2) force on the brake pedal. Participants placed their hands at the steering wheel at the 10 (left hand) and 2'o clock (right hand) positions. The right foot rested on the gas pedal (Fig. 1a). Participants flexed the hip joint to ~90° with 10° abduction, flexed the knee to ~45°, and plantarflexed the ankle to ~15°.

2.3.2. Simulated reactive driving task

The monitor displayed a crowded city driving condition (Fig. 1b). The driver's car was located in the middle lane among three lanes. There were two cars in the left lane (one in front the other), one car in the middle lane, and two cars in the right lane (one in front of the other). All five cars were located ahead of the driver's car from the driver's viewpoint.

The first task of the participants was to track a target box (solid grey square) with a dotted blue line box (gas pedal position). The target square and dotted line box had the same centroid (Fig. 1b). To match the targeted grey square participants had to plantarflex

Fig. 1. Reactive driving task and visual feedback. (b) From the visual feedback, participants see five cars (two in the left, one in the middle, and two in the right lanes) in front and two square boxes. (a) Participants tracked a visual target (gray square box) by controlling the gas pedal (a box with dotted lines). When the brake lights of the car in front turned red at a random time, participants react as fast as possible by moving the foot from the gas pedal to the brake pedal and attempting to produce a braking force equal to 40 N.

the right ankle 20° and press on the gas pedal (Fig. 1a). Thus, pressing the gas pedal made the size of the dotted line box smaller and releasing the foot from the gas pedal made the dotted line box size bigger. The targeted grey square and dotted line box (performance) were displayed above the dashboard from the driver's point of view.

The second task of the participants was to react as fast as possible to the brake lights of the car ahead turning red. This occurred while matching the targeted grey square with the dotted line square (constant pressure on the gas pedal). While controlling the gas pedal, the brake lights of the car(s) located in the visual field turned red at a random time for 0.5 s. Participants reacted to this visual stimulus as fast as possible by moving their foot from the gas pedal to the brake pedal. Their goal was to exert a brake force of 40 N (Fig. 1a). After each trial, participants received performance feedback containing the reaction time (seconds) and the brake force (N) in order to make future adjustments.

2.3.3. Visual information processing manipulation

We manipulated the required information processing (cognitive load) by changing the task from a simple reaction time task to a go/no-go task with more possible visual stimuli. During the *simple reaction time task*, participants focused on only one car, which was located in the center of the visual display (Fig. 1). The brake lights of that car turned red randomly in 33 trials. Thus, the simple reaction time condition had a single stimulus on a fixed location and only a "Go" scenario. During the *go/no-go task*, participants focused on 5 different cars (two in the left lane, one in the center, and two in the right lane). All cars were located at different distances. There were a total of 67 trials in this condition. For 33/67 trials, participants responded when the brake lights of one car

turned red ("Go" trials) while the other four turned blue. For 34/67 trials, the brake lights of all five cars turned blue and participants were not supposed to respond ("No go" trials). The order of the "Go" and "No go" trials was random. Similarly, the location of the red brake lights was randomized among the five cars in each trial. During the "No go" trials, participants were not supposed to react and continue controlling the gas pedal. Therefore, the go/no-go task increased visual information processing because it required scanning of a wider visual area (1 vs. 5 cars), increased response uncertainty ("Go" only vs. "Go" or "No go"), and increased distractors (blue color). The number of total trials matched the number of "Go" trials for the two tasks. We gave equal number of trials for "Go" (33 trials) and "No go" (34 trials) and we used random car location as a stimuli for the "Go" trials ("Go" trials for each car = 6–7 trials).

2.3.4. Gas pedal position and brake force measurement

The gas pedal position was measured using a CSR Elite Pedal (Fanatec, Endor AG, Germany). The brake pedal force was measured using a force transducer (Model LAU200, 100 lb capacity, FUTEK Advanced Sensor Technology, Irvine, CA). Both signals were sampled at 1 kHz with NI-DAQ board (Model USB6218, National Instruments, Austin, TX, USA) and stored on a personal computer.

2.3.5. EMG measurement

Muscle activity from the tibialis anterior was measured using wireless surface electromyography electrodes (Delsys Trigno, Delsys, Boston, MA). All EMG signals were sampled at 1 kHz with NI-DAQ board (Model USB6218, National Instruments, Austin, TX, USA) and stored on a personal computer.

2.4. Data analysis

2.4.1. Reactive driving performance

The three components of the reactive driving task performance included premotor response time, motor response time, and brake force error (Fig. 2). Premotor response time was quantified as the time between the onset of the visual stimulus and the onset of the tibialis anterior muscle activity. Motor response time was quantified as the time between the onset of the tibialis anterior muscle activity and the brake force onset. Brake force error was quantified as the error in the exerted force on the brake pedal (peak force) relative to the target force (40 N).

A greater score on any of the above components indicates a poorer performance. These three components were specifically chosen to compute the reactive driving score because the participants were instructed to modulate their performance by quickly reacting to the visual stimulus (premotor response time), quickly moving the foot from the gas pedal to the brake pedal (motor response time), and applying a precise amount of brake force (brake pedal error).
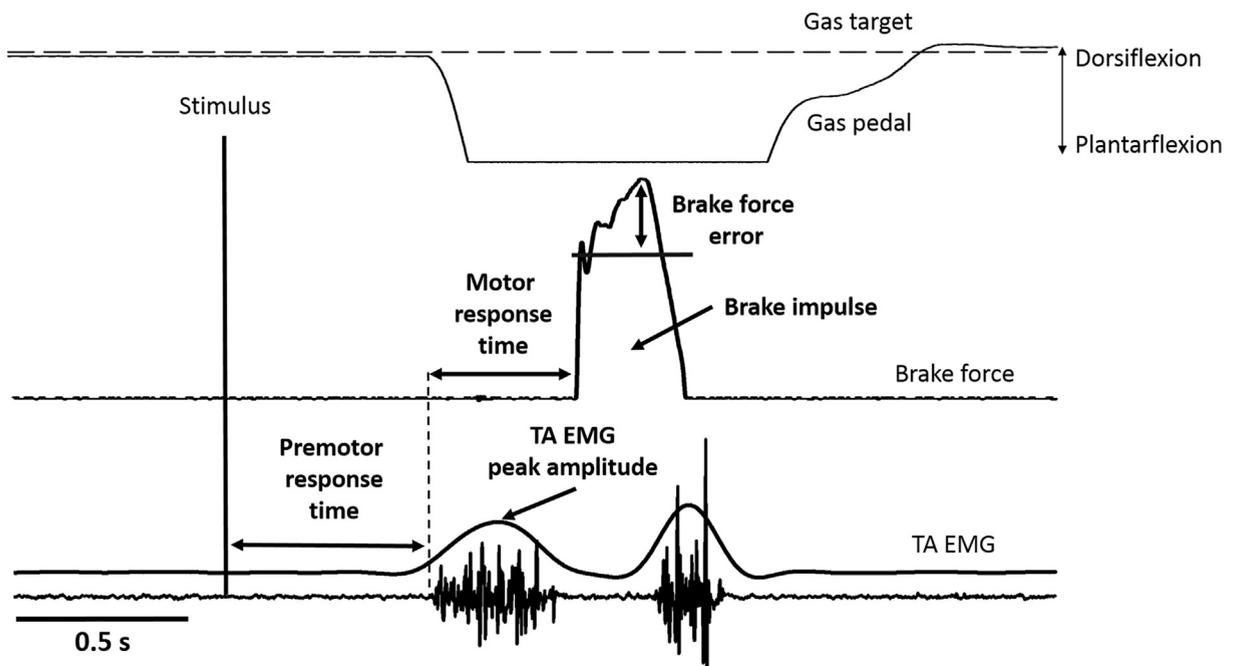

Fig. 2. Quantification of the reactive driving. We quantified the following performance variables from the reactive driving task: 1) Premotor response time: time between the onset of the visual stimulus and the onset of the tibialis anterior muscle activity. 2) Motor response time: time between the onset of the tibialis anterior muscle activity and the onset of brake force. 3) Brake force error: the error in the exerted peak force relative to the targeted force (40 N) on the brake pedal. 4) Brake impulse variability: the standard deviation of the brake impulse produced across the trials. 5) TA EMG peak amplitude variability: the standard deviation of the smoothed EMG peak amplitude across trials.

We quantified the overall reactive driving score as the average of the three reactive driving component scores (sub-scores). For normalization, we computed the average value from all participants for the simple reaction time task and the Go/No-go reaction time task and normalized each sub-score for each participant by dividing individual scores with the group average. We computed the overall reactive driving score for each participant by averaging the three normalized sub-scores. Thus, a higher reactive driving score reflected worse reactive driving performance.

2.4.2. Brake impulse variability

We quantified motor output variability as the standard deviation (SD) of the brake impulse produced by each participant across the trials.

2.4.3. Variability of muscle activation (TA EMG peak amplitude variability)

We quantified variability of muscle activation as the standard deviation (SD) of the tibialis anterior EMG peak amplitude generated by each participant across the trials. To measure the peak amplitude of TA EMG, we performed the following procedures from the raw EMG signal: 1) the interference (raw) EMG was cut from the stimulus onset to brake force onset; 2) the cut EMG was detrended and rectified; 3) the rectified EMG was smoothed by applying a Butterworth 2nd order low-pass filter with a cutoff frequency of 8 Hz; 4) the amplitude of the smoothed signal was calculated in each trial; and 5) the SD of the EMG peak amplitude was calculated across trials.

2.5. Statistics

The major dependent variables were: 1) reactive driving score, 2) components of reactive driving performance (premotor response time, motor response time, and brake force error), 3) brake impulse variability, and 4) TA EMG peak amplitude variability. The independent variables were the age groups and conditions (simple reaction task vs. Go/No-Go task). We used a two-way mixed ANOVA (2 age groups × 2 visual loads) to examine the age-associated differences in the dependent variables with repeated measures on visual loads. We used independent samples t-test to examine the age-associated differences in errors during "Go" (False negative) and "No go" task (False positive).

We used a stepwise multiple-linear regression model to determine which parameter of the reactive driving performance contributes the most to the reactive driving score. In addition, we used simple linear regression models to determine the contribution of brake impulse variability and TA EMG peak amplitude variability to the reactive driving score and brake force error. The goodness-of-fit of the model, which indicates how well the independent variables predict dependent variables, was given by the squared multiple correlations (R^2), Durbin Watson statistic, and part correlation coefficients that demonstrate the unique contribution of the predictors to the criterion variables. We performed all statistical tests with the IBM SPSS Statistics 24.0 statistical package (IBM Corp., Armonk, NY, USA). Significant interactions from the ANOVA were followed by appropriate post-hoc analyses. For example, age-associated differences were followed with an independent t-test, and the differences across tasks were examined with a paired t-test. The alpha level for all statistical tests was set at 0.05 and adjusted for multiple comparisons with Bonferroni corrections. Data are reported as mean ± SD within the text and as mean ± standard error of the mean (SEM) in the figures. Only the significant main effects and interactions are presented, unless otherwise noted.

3. Results

3.1. Visual information processing and reactive driving performance

Premotor response time was the time between the onset of the visual stimulus and the onset of the TA muscle activity. There was a significant age group × condition interaction on premotor response time ($F_{1,28} = 12.4$, P = 0.001, $\eta^2_p = 0.31$; Fig. 3a) and a significant main effect for condition ($F_{1,28} = 507.8$, P < 0.001) and age ($F_{1,28} = 28.26$, P < 0.001). Post-hoc analysis indicated that both young and older adults exhibited a significant increase in premotor response time with the increase in visual information processing (Young: Low = 319.7 ± 21.7 ms, High = 596.9 ± 49.5 ms, t = 24.44, P < 0.001, $d = 6.53$, Older: Low = 384.8 ± 61.1 ms, High = 764.7 ± 114.2 ms, t = 14.98, P < 0.001, $d = 3.75$), while the age-associated differences were greater at the high visual information processing condition (Low: t = 3.99, P = 0.001, $d = 1.42$, High: t = 5.33, P < 0.001, $d = 1.91$).

Motor response time was the time between the onset of the TA muscle activity and the brake force onset. There was a significant age group × condition interaction on motor response time ($F_{1,28} = 8.89$, P = 0.006, $\eta^2_p = 0.24$; Fig. 3b) and a significant main effect for condition ($F_{1,28} = 11.12$, P = 0.002) but not for age ($F_{1,28} = 2.92$, P = 0.099). Post-hoc analysis indicated that the age-associated differences in motor response time was significant at the high visual information processing condition (Young = 320.5 ± 74.6 ms, Older = 399.2 ± 93.5 ms, t = 2.52, P = 0.018, $d = 0.91$) but not at the low visual information processing condition (Young = 316.1 ± 72.47 ms, Older = 319.9 ± 50.2 ms, t = 0.17, P = 0.864, $d = 0.06$). Only older adults exhibited a significant increase in motor response time with visual information processing (t = 4.13, P = 0.001, $d = 1.03$).

Brake force error was the error in the exerted force on the brake pedal (peak force) relative to the targeted force (40 N). There was a significant age group × condition interaction on brake force error ($F_{1,28} = 5.28$, P = 0.029, $\eta^2_p = 0.16$; Fig. 3c) and a significant main effect for age ($F_{1,28} = 6.81$, P = 0.014) but not for condition ($F_{1,28} = 2.83$, P = 0.103). Post-hoc analysis indicated that older adults exhibited significantly greater brake force error for the high visual information processing condition (Young = 6.3 ± 2.7 N, Older = 11.7 ± 5.7 N, t = 3.25, P = 0.003, $d = 1.21$) but not for the low visual information processing condition
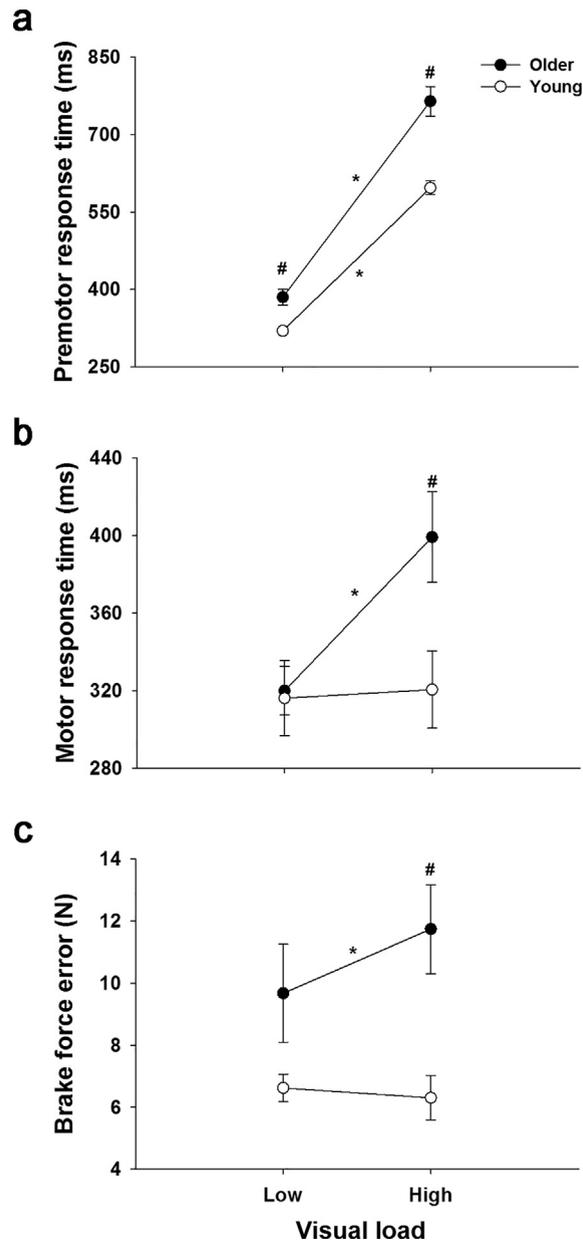
Fig. 3. Visual load and components of reactive driving performance. (a) Visual load increased premotor response time in both young and older adults. The increase in premotor time with visual load was greater in older adults. (b) Visual load increased motor response time in older adults, but not in young adults. (c) Visual load increased brake force error in older adults, but not in young adults.

(Young = 6.6 ± 1.7 N, Older = 9.7 ± 6.3 N, t = 1.75, P = 0.09, d = 0.66). Only older adults exhibited a significant increase in brake force error with visual information processing (t = 2.71, P = 0.016, d = 0.68).

The overall reactive driving score was the average score of the premotor response time, motor response time, and brake force error. A higher reactive driving score indicates a poorer reactive driving performance. The effect of visual information processing on the reactive driving performance for young and older adults is shown in Fig. 4a. There was a significant age group × condition interaction on reactive driving score ($F_{1,28}$ = 19.62, P < 0.001, η^2_p = 0.41; Fig. 4a) and a significant main effect for condition ($F_{1,28}$ = 160.56, P < 0.001) and age ($F_{1,28}$ = 19.54, P < 0.001). Post-hoc analysis indicated that both young and older adults exhibited a significant increase with visual information processing (Young: Low = 89.9 ± 11.7%, High = 115.2 ± 13.3%, t = 6.77, P < 0.001, d = 1.80, Older: Low = 108.8 ± 26.2%, High = 161.2 ± 28.3%, t = 11.13, P < 0.001, d = 2.78) but the age-associated difference was greater at high visual information processing condition (Low: t = 2.48, P = 0.019, d = 0.93, High: t = 5.55, P < 0.001, d = 2.08).

To determine which component of the reactive driving performance contributes the most to the age-associated changes in reactive
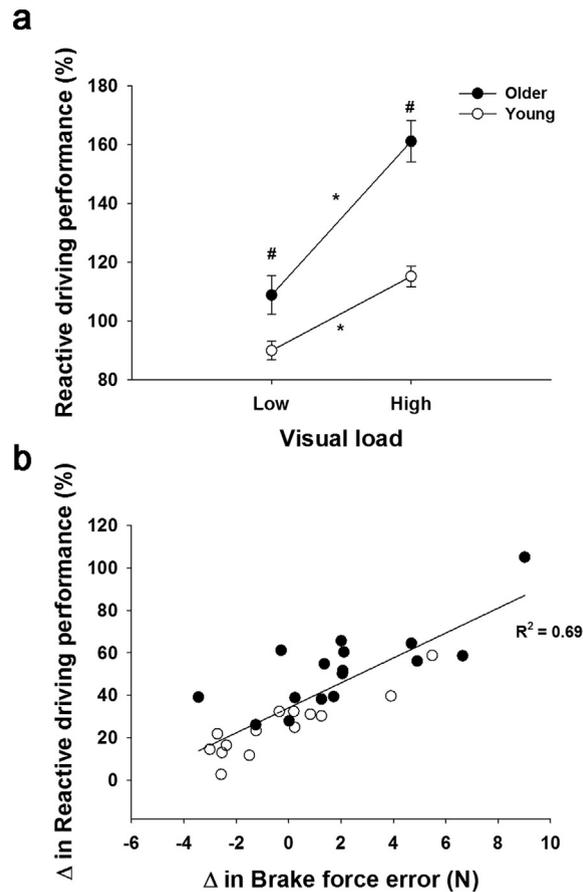
Fig. 4. Reactive driving performance and brake force error. (a) Visual load deteriorated reactive driving for both young and older adults. However, the impairment in reactive driving score with visual load was greater in older adults. (b) The change in reactive driving performance with visual load was predicted from the change in brake force error ($R^2 = 0.69$).

driving score, a multiple stepwise-linear regression was performed. The independent variables were the changes in premotor response time, motor response time, and brake force error and the dependent variable was the change in reactive driving score from low to high visual information processing condition. All three variables were associated with reactive driving performance (premotor response time: $R^2 = 0.46$, motor response time: $R^2 = 0.42$, brake force error: $R^2 = 0.69$). The best model included only the brake force error as a predictor of the reactive driving score ($R^2 = 0.69$, Durbin Watson = 1.141, p < 0.001, Fig. 4b).

We also quantified the false positive and false negative error rate. Older adults exhibited significantly greater number of false positives compared with young adults (Young = 0.15 ± 0.55%, Older = 6.9 ± 6.7%, t = 4.00, P < 0.001). Older adults also exhibited significantly greater number of false negatives compared with young adults (Young = 0.87 ± 1.31%, Older = 2.5 ± 2.6%, t = 2.22, P < 0.037).

3.2. Variability and reactive driving performance

Our measure for motor output variability was the trial-to-trial brake impulse variability. We examined the correlation between the change in brake impulse variability and the change in brake force error (strongest predictor of reactive driving) and reactive driving score from low to high visual information processing condition. The change in brake impulse variability with increased visual information processing was correlated with the change in brake force error ($R^2 = 0.51$, Durbin Watson = 2.476, p < 0.001, Fig. 5a) and reactive driving score ($R^2 = 0.63$, Durbin Watson = 1.287, p < 0.001, Fig. 5b).

Our measure for muscle activation variability was the trial-to-trial TA EMG peak amplitude variability. There was a significant age group × condition interaction on TA EMG peak amplitude variability ($F_{1,28} = 5.132$, P = 0.032, $\eta^2_p = 0.16$) but not a significant main effect for condition ($F_{1,28} = 2.54$, P = 0.122) and age ($F_{1,28} = 0.24$, P = 0.627). Post-hoc analysis indicated that the condition associated differences in TA EMG peak amplitude variability was significant in older adults (high = 0.018 ± 0.007 mV, Low = 0.015 ± 0.007 mV, t = 2.66, P = 0.018, d = 0.66) but not in young adults (high = 0.015 ± 0.005 mV, Low = 0.016 ± 0.006 mV, t = 0.499, P = 0.626, d = 0.13). Age-associated differences were not significant during both low (t = 0.22, P = 0.827) and high visual information processing conditions (t = 1.168, P = 0.253). The change in TA EMG peak
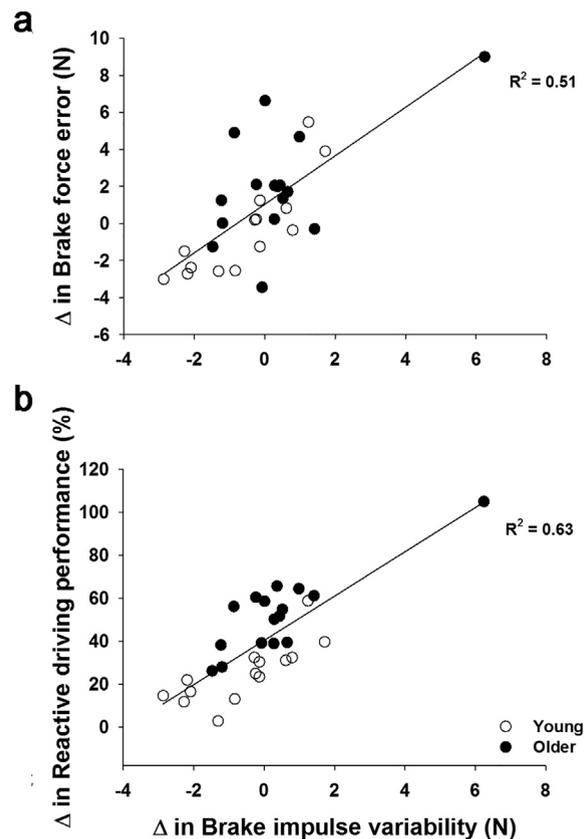
Fig. 5. Motor output variability and reactive driving performance. (a) The change in brake force error with visual load was predicted from the change in brake impulse variability ($R^2 = 0.51$). (b) The change in reactive driving performance with visual load was predicted from the change in brake impulse variability ($R^2 = 0.63$).

amplitude variability was greater in older adults (Young = −0.0005 ± 0.0038 mV, Older = 0.0030 ± 0.0044 mV, t = 2.26, P = 0.031). We also examined the correlation between the change in TA EMG peak amplitude variability and the change in brake impulse variability and the change in reactive driving score from low to high visual information processing condition. The change in TA EMG peak amplitude variability correlated with the change in brake impulse variability ($R^2 = 0.41$, Durbin Watson = 1.549, p < 0.001, Fig. 6a), and reactive driving score ($R^2 = 0.48$, Durbin Watson = 1.288, p < 0.001, Fig. 6b).

4. Discussion

In this project, we examined whether increased visual information processing increases muscle activation variability in older adults and impairs their ability to react as fast and as precisely as young adults in a simulated driving task. Here, we manipulated visual information processing in young and older adults by increasing the visual load and examined its influence on a simulated driving task. We provide novel evidence that increasing the visual information processing increases muscle activation variability and consequently impairs the ability of older adults to react equally well to young adults during a simulated driving task.

4.1. Aging and reactive driving performance with cognitive load

Car following and the ability to react to unexpected visual stimuli (e.g. rear brake lights) is an important component of driving. It requires fast and accurate visual information processing and precise motor execution (Perryman & Fitten, 1996). Recently, we have demonstrated that the age-associated increase in motor output variability is a significant contributor to impaired reactive driving performance in older adults (Lodha et al., 2016). Driving conditions vary and reactive driving can become more challenging in environments that require more visual information processing. This led us to ask the following question: "Does increased visual information processing exacerbate motor output variability and consequently reactive driving performance in older adults?"

Numerous studies have demonstrated that increasing the amount of visual information results in greater motor output variability in older adults (Baweja et al., 2012; Kennedy & Christou, 2011). Nonetheless, these studies involve constant isometric contractions and isolated single joint movements. The functional significance of the interaction between increased visual information processing and motor output variability in older adults remained elusive. For the first time, we demonstrate that the increase in motor output
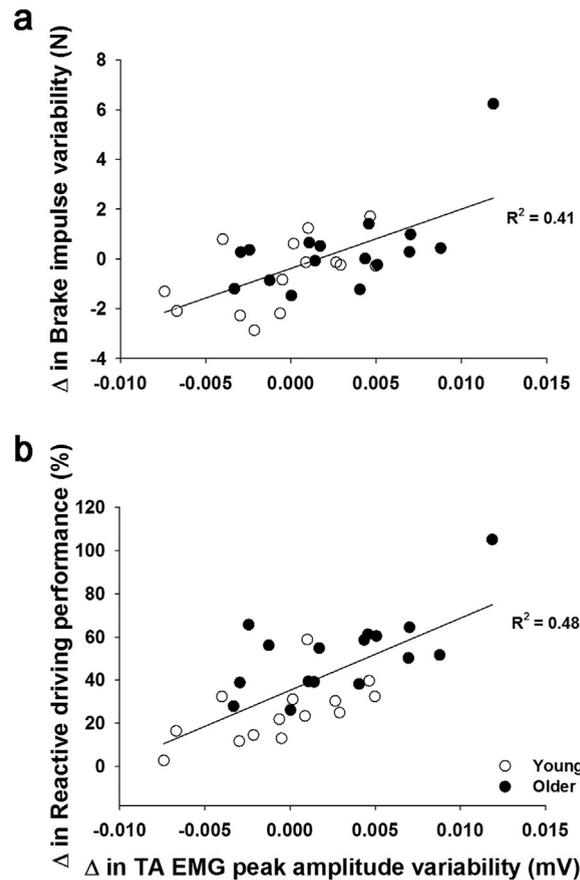
Fig. 6. Muscle activation variability and reactive driving performance. (a) The change in brake impulse variability with visual load was predicted from the change in TA EMG peak amplitude variability ($R^2 = 0.41$). (b) The change in reactive driving performance with visual load was predicted from the change in TA EMG peak amplitude variability ($R^2 = 0.48$).

variability with increased visual information has functional consequences. Specifically, we increased visual information processing by asking older adults to respond during two visual load conditions. The low visual load condition was a "Go" task and involved responding to a consistent visual stimulus that occurred at the same location. The high visual load condition was a "Go/No go" task and involved responding to a stimulus that occurred randomly at various locations. The change in visual load increased the premotor response time by ~200%, which demonstrates that our manipulation significantly increased visual information processing. Most importantly, we show that such manipulation resulted in impaired driving performance, as quantified by the ability of the participants to respond as fast and as accurately as possible. Therefore, we provide evidence that increasing visual information processing impairs reactive driving more in older adults.

This finding leads to the following important question: "How does increased visual information processing results in impaired reactive driving performance in older adults?" Our results suggest that increased visual information processing increases both motor output variability (brake impulse variability), and muscle activation variability (TA EMG peak amplitude variability), especially in older adults. We show that the impairment in reactive driving performance was correlated to both motor output variability and muscle activation variability. In addition, the increase in motor output variability (brake impulse variability) correlated with an increase in muscle activation variability (TA EMG peak variability). Therefore, we conclude that increased visual information processing increases muscle activation variability, which increases motor output variability.

4.2. Considerations

An important limitation of this work is that the findings are based on a simulated reactive driving task. It was essential to use a simulated task so that we could control for extraneous variables (e.g. number of stimuli presented; driving conditions; distractors unrelated to the task) that could influence our results. Nonetheless, our findings are limited to this simulated driving task and could vary in real driving situations with more stimuli and more complex decision making. Future studies should expand these findings to real driving scenarios.

Another consideration is the argument that the impairment to executive function in older adults is exaggerated (Verhaeghen, 2011). This occurs because more challenging tasks to executive function lead to greater absolute differences between young and older

adults. However, when the relative change is examined, young and older adults exhibit similar impairments in executive function during tasks that are more difficult. Indeed, our executive function outcomes, such as premotor response time, showed similar relative increase for young (180%) and older (190%) adults. Nonetheless, for outcomes that involved the motor system, the relative differences were greater for older adults than young adults (motor response time: 125 vs 100%; brake force error: 120 vs. 95%). Therefore, age-associated differences appear to exacerbate more for tasks that involve the motor system than executive function. Future meta-analysis studies should investigate whether the relative changes between young and older adults differ for executive function and motor output.

In summary, we provide novel evidence that increasing the visual information processing increases muscle activation variability and consequently impairs the ability of older adults to react equally well to young adults during a simulated driving task. For the first time in the aging literature we show that the increased motor output variability induced by increased visual information in older adults has functional consequences. We conclude that rehabilitation protocols in older adults should consider the effect of visual information processing.

Funding

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