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ORIGINAL RESEARCH

Age-related slowing of lower limbs visuomotor reaction time in 60–79 years old women

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Abstract

Background: There is limited knowledge on the latency of eye-foot reaction in the elderly, although some of their activities of daily living demand a quick response of the lower limbs. **Objective:** The aim of the study was to examine age-related changes in simple visual lower limb reaction time (RT) and RT variability in females across the 7th and 8th decades of their lives. **Methods:** Women aged 60–79 years (N = 66) performed the sidestep simple eye-foot reaction test using the optoelectronic device Optogait, including 24 trials for each leg. **Results:** The older age group of women (70–79 years) achieved significantly longer RT than the younger group (60–69 years). Across the entire sample, RT significantly correlated with age, but RT variability did not change with the age of women. Functional laterality of lower limbs did not prove to be a significant factor for both RT and RT variability. **Conclusions:** The study showed progressive slowing of eye-foot reaction with the age of women from 60 to 79 years, but no age-related changes in neurobiological disturbances indicated by RT variability. In the context of the prolongation of working life today in European countries, the results suggest the need to respect the natural aging of cognitive-motor functions.

Keywords: eye-foot reaction, females, reaction time variability, functional laterality

Introduction

Human aging is associated with deterioration in cognitive functions such as attention control, working memory, and executive control (Bedard et al., 2002; Pliatsikas et al., 2019), as well as a decline in the brain's information processing capacity (Blomkvist et al., 2017). Information processing is considered a fundamental basis for human cognition (Macpherson & Horak, 2013). It has been suggested that age-related deterioration in information processing underlies the cognitive changes experienced by older adults (Eckert et al., 2010). A decrease in the speed and accuracy of information processing can strongly affect the quality of an individual's interaction with their physical and social environment.

Simple and choice visual and auditory reaction times (RT) that indicate information processing speed have been reported to prolong with age (Blomkvist et al., 2017; Hardwick et al., 2022), with more profound prolongation after 60 years of age (Dykiert et al., 2012). Age-related declines in information processing speed were found to be uniquely related to the cerebellar pattern of gray matter and white matter (Eckert et al., 2010) and contributed by motor cortical processes (Marusic et al., 2022). These processes contribute most strongly to the slowing of simple RT (SRT) in advanced age (Marusic et al., 2022).

Neuropsychological assessment of reaction abilities in both clinics and research usually requires an individual's motor responses with a hand that involve the eye-hand neural circuit. However, deterioration of information processing in the brain can be critical for psychomotor performance of lower limbs, such as quick stepping in physical activities, maintaining balance, or brake reaction while driving a car. Longer brake RT in brake pedal reaction tasks in older individuals has been reported (Ashok et al., 2016; Shin & Lee, 2012). Doroudgar et al. (2017) found an association of longer visual SRT with more collisions and slower driving in a driving simulation in individuals aged ≥ 60 years as compared to younger subjects. Lower-limb RT to visual stimuli discriminated well between single and multiple fallers (Lord & Fitzpatrick, 2001; Maver et al., 2011).

The above-mentioned evidence has supported the assumption that the speed of visuomotor reaction with lower limbs may be more important for daily living than upper-limb movement reaction. Researchers have suggested that neuromotor processes involved in motor responses of lower limbs to stimuli may not configure in the same way as the eye-hand system (Brinkman et al., 2020). From a neuroanatomical perspective, there are different locations in the brain cortex for motor control of lower limbs and upper limb parts such as the forearm, wrist, and fingers (Meier et

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al., 2008). Further, the representation of the upper limbs in the primary motor cortex is larger compared to the lower limbs. This is related to the higher density of cutaneous motor receptors in the upper limbs needed for fine motor control and high precision of movement (Meier et al., 2008). It could also be suggested that there are differences in the central generation of neuromuscular coordination patterns to execute motor action with a foot, such as stepping or plantar flexion, compared to simpler movements like pressing a button with a finger, typically used in RT examinations. The electrophysiological study by Tinkhauser et al. (2019) found that neural processing in the basal ganglia is differentially organized in the spectral and spatial domains for movement with a lower and upper limb. Furthermore, a longer efferent neural pathway to leg muscles could theoretically be associated with larger neural noise.

Age-related changes in neurocognitive processing and motor performance, especially visuomotor RT, are well documented. Anatomical and neurophysiological differences between upper and lower limbs suggest distinct reaction capabilities, with evidence indicating that lower limb visuomotor responses may hold greater functional and clinical relevance in certain contexts. Intraindividual RT variability is recognized as a sensitive marker of underlying neurobiological disturbances linked to physical and cognitive decline in older adults. Empirical research shows that increases in intraindividual RT variability with age across cognitive tasks (Bunce et al., 2017; Hultsch et al., 2002; West et al., 2002).

Functional laterality, or limb dominance, affects upper limb RT, where dominant hands typically exhibit faster RTs in younger adults (Chouamo et al., 2020). However, evidence on lower limb laterality effects is sparse and inconsistent. For instance, Blomkvist et al. (2017) found no significant RT differences between dominant and non-dominant hands or legs in individuals aged 20–99, though their choice RT task involving response selection complicates direct comparison.

This study targets females aged 60 to 79 due to sex-specific neurocognitive aging and motor patterns requiring focused investigation. Females represent a substantial portion of the aging population and face a higher risk of motor and cognitive impairments, justifying their exclusive inclusion (Christensen et al., 2024).

The aim of the study was to examine age-related changes in simple visual lower limb RT and intraindividual RT variability in females across the 7th and 8th decades of their lives.

Methods

Participants

The participants were visitors of the Day for Health, organized by the Senior-Fitness Organization of the Czech Republic. Voluntary female participants performed a side-step simple eye-foot reaction test. For the study, data from 66 participants who completed the entire reaction task correctly, and met the inclusion criterion of age (60–79 years) and the exclusion criteria as follows were submitted for analysis: neurological and psychotic diseases, mental disorders, severe orthopedic difficulties, other neuromuscular diseases of lower limbs including neuropathy, hip, knee, or ankle surgery in the last half year, sclerosis, complicated hypertension, severe gastritis, non-corrected visual and hearing impairments, malignant tumors, 2nd and 3rd degree of urinary incontinence and stool incontinence, current drug therapy including medication affecting attention, acute or chronic pain, and substantially shorter and/or worse quality of sleep than usual on the night before testing. These criteria were checked using a health questionnaire derived from the White Book on Physical and Rehabilitation Medicine in Europe (Gutenbrunner et al., 2007) and filled in by participants.

Participants took part in the reaction time (RT) testing voluntarily and signed informed consent before the measurement. They were not informed about the research purpose of the study. Several days after the testing, each participant received her reaction ability results via email. The study was approved by the College Ethics Committee (code: SV-V-2-2022). The sample of 66 women was divided into two age groups: A group in the 7th decade (60–69 years) and a group in the 8th decade of age (70–79 years), see Table 1.

The testing session and procedures

Before a participant performed the test, the functional laterality of her lower limbs was determined using five tasks: kicking a tennis ball at a target, stepping up onto a stair, standing on one foot, hopping on one leg, and performing a one-leg vertical countermovement jump. A dominant limb was identified as the limb being the mobilizing or leading limb, and as a limb that was not used for support or propulsion in the particular motor tasks. Specifically, the

Table 1 Characteristics of both age groups of women

Characteristics	60–69 years old	70–79 years old
n	36	30
Age (years)[a]	66.6 ± 3.1	74.4 ± 2.7
Body weight (kg)	69.3 ± 11.8	71.0 ± 11.9
Body height (cm)	165.0 ± 6.6	163.2 ± 6.4
Body mass index (kg/m^2)	25.5 ± 4.2	26.6 ± 3.9
Functional dominance of right foot	32 (88.9%)	27 (90.0%)
Vertigo, migraine	2 (5.6%)	4 (13.3%)
Diabetes mellitus	7 (19.4%)	1 (3.3%)
Asthma	2 (5.6%)	3 (10.0%)
Corrected hypertension	11 (30.6%)	18 (60.0%)
Cardiac problems, arrhythmia	5 (13.9%)	8 (26.7%)
Stroke suffered	0 (0.0%)	1 (3.3%)
Weak neurological problems	7 (19.4%)	1 (3.3%)
Endocrinal problems	2 (5.6%)	2 (6.7%)
Hearing difficulty	2 (5.6%)	5 (16.7%)
Current regular physical activity	6 (16.7%)	3 (10.0%)
Education		
Tertiary	11 (30.6%)	11 (36.7%)
Secondary	24 (66.7%)	18 (60.0%)
Primary	1 (2.8%)	1 (3.3%)

Note. The values are presented as mean ± standard deviation or as *n* (percentage). [a]The median age was 68 years for the younger group and 75 years for the older group.

limb used for kicking a ball, the limb initiating a step up onto a stair, the limb not supporting one-leg standing, the non-propulsive limb for hopping, and the leading limb for a vertical jump were considered as the limb with functional dominance for a given motor task. Functional laterality was determined when a functional dominance of a given leg was manifested for at least three motor tasks. The classification of functional laterality of lower limbs has been conducted according to the previously used methods (Gabbard & Iteya, 1996; Ilnicka et al., 2013). An instructor provided each participant with a brief instruction and a demonstration of the task.

After determining functional laterality, the participant performed the computer-based sidestep simple eye-foot reaction test (SSEFR test) using the optoelectronic device Optogait (Version 1.3.20.0; Microgate, Bolzano, Italy). Two transmitting and two receiving bars (100 × 8 cm) of this device were joined together. Each bar contains 96 light-emitting or light-receiving diodes (one every centimeter) located 3 mm above ground level. The transmitting and receiving bars were placed parallel on the ground. A participant stood with shoulder-width apart (total distance between the inner sides of feet 18 cm), one bar going between two feet at a distance of 5 cm from the inner side of each sole, both limbs bent at a knee angle of approximately 70-80 degrees, both heels flat on the floor, and arms down along the body. The distance of the second bar was 5 cm from the lateral side of the sole of the stepping foot. Timing mechanism of this device measures RTs as the interval between the moment when the stimulus appears on the computer screen and the moment when the infrared beams emitted from the transmitting bar are no longer interrupted by the foot when it is raised more than 3 mm above ground level.

A participant was instructed to bear equal weight on each leg. A Lenovo V15 G4 IRU notebook (Lenovo, Hong Kong, China) with a screen size of 15.6 inches and a resolution of 1920 × 1080 pixels was placed on a table at a height of 120 cm and a distance of 1.5 m from the participant. The task for the participant was to respond to the target stimulus – a green circle (7 cm in diameter at the center of the screen) as fast as possible by performing a sidestep over the second parallel bar and then returning the leg back to the starting position, marked by a thin yellow tape. The SSEFR test involved 24 reaction trials for each lower limb, designed into four blocks with 12 trials per block. Responses in the first and third blocks were performed using the same leg (dominant or non-dominant leg), and in the second and fourth blocks, the other leg (non-dominant or dominant) was used. The order of the blocks was counterbalanced among participants. For responses with the right leg, participants performed sidesteps over the right bar while standing above the left bar, and for responses with the left leg, over the left bar. Within each block, the interval between stimuli varied randomly among 3, 4, 5, and 6 seconds, with each interval repeated three times in a row (e.g., 3, 3, 3, 4, 4, 4, 5, 5, 5, 6, 6, 6 seconds). The order of these four intervals between stimuli was balanced among participants. Before the test trials, a demonstration and six practice trials were conducted for each foot. Data were sampled at the frequency of 1000 Hz using the software OptoGait (Version 1.3.20.0; Microgate, Bolzano, Italy).

The following variables were assessed: median RT for responses with a dominant and non-dominant foot (MdnRT-dom, MdnRT-nondom) as the measures of speed of information processing related to the neural eye-foot system, and intraindividual variability of RTs indicated by standard deviation (iRTSD) and coefficient of variation of intraindividual RTs in percentage (iRTCV%). RTs < 110 ms and foot responses before a stimulus occurred were assessed as incorrect responses. Data from participants who committed more than five incorrect responses for a given foot were not included in the analysis.

Data analysis

In the first step, outliers of RTs in each participant were identified as any observation outside the range of Tukey's fences: [Q1 – 1.5(Q3–Q1), Q3 + 1.5(Q3–Q1)], where Q1 and Q3 are the lower and upper quartiles. The outliers were excluded from the calculation of the measures. Then, the Shapiro-Wilk test showed that the MdnRT of participants for both the dominant and non-dominant leg was not significantly different from a normal data distribution (α = .05).

To examine the effects of age and functional laterality of the lower limb on MdnRT, iRTSD, and iRTCV%, a 2 (group: 60–69 vs. 70–79 years) × 2 (functional laterality of lower limbs: dominant vs. non-dominant leg) mixed-design analysis of variance (ANOVA) with repeated measures on the second factor was conducted. Levene's test showed that the assumptions of equality of error variances of MdnRT, iRTSD, and iRTCV% for both dominant and non-dominant leg in the two age groups were not violated (p = .967 and .509, p = .367 and .404, p =.214 and .749 respectively). Effect sizes were calculated using partial eta squared (η_p^2), with an interpretation of η_p^2 =.01, .06, and .14 as small, medium, and large effects, respectively. Regression analysis was used to analyze the relationship between age and RT across all ages. A level of α = .05 was set for all tests. Data analyses were conducted with IBM SPSS Statistics (Version 24; IBM, Armonk, NJ, USA).

Results

Effects on stepping reaction time

The results of SSEFR test are presented in Table 2. The results of the analysis of variance showed a statistically significant effect of the age group on MdnRT, $F(1, 64)$ = 6.499, p = .013, η_p^2 = .092, regardless of the functional laterality of lower limbs. Functional laterality of lower limbs was not a significant factor for MdnRT, $F(1, 64)$ = 0.612, p = .437, η_p^2 = .009. Also, the interaction of the age group and the functional laterality of lower limbs was not significant, $F(1, 64)$ = 0.499, p = .505, η_p^2 = .007. The group aged 70–79 years exhibited longer MdnRT compared to the group aged 60–69 years (Table 2), $F(1, 64)$ = 4.676, p = .034, η_p^2 = .087.

The regression analysis showed significant dependence of MdnRT on age for the dominant leg, r = .261, adjusted r^2 = .054, p = .034, SEE = 55.9 ms, 10.0%, and the non-dominant leg, r = .308, adjusted r^2 = .081, p = .012, SEE = 56.7 ms, 10.2% (Figure 1).

Effects on intraindividual sidestep reaction time variability

iRTSD was not significantly different between the group aged 60–69 years and the older group aged 70–79 years (Table 2), $F(1, 64) = 0.004$, $p = .952$, $\eta_p^2 = .000$. The effect of functional laterality of lower limbs and its interaction with the age group was also not significant for RTs, $F(1, 64) = 0.077$, $p = .782$, $\eta_p^2 = .001$, and $F(1, 64) = 0.025$, $p = .874$, $\eta_p^2 = .000$, respectively. Non-significant regression of iRTSD on age was found for the reaction with the dominant leg, r = .118, adjusted r^2 = –.002, p = .346, SEE = 19.6 ms, and the non-dominant leg, r = .153, adjusted r^2 = .008, p = .219, SEE = 19.3 ms.

Intraindividual RT variability expressed as iRTCV% was also not significantly affected by the age group, $F(1, 64) = 1.698$, $p = .197$, $\eta_p^2 = .026$ (Table 2). The effect of functional laterality of lower limbs was not significant for iRTCV%, $F(1, 64) = 0.025$, $p = .874$, $\eta_p^2 = .000$, nor was its interaction with the age group, $F(1, 64) = 0.000$, $p = .988$, $\eta_p^2 = .000$.

iRTCV% for the dominant and non-dominant leg were non-significantly regressed on age, r = .027, adjusted r^2 = –.122, p = .831, SEE = 3.3%, and r = .029, adjusted r^2 = –.015, p = .820, SEE = 3.2%, respectively.

Table 2 Results of the sidestep simple eye-foot reaction test performed with a dominant and non-dominant foot in both age groups

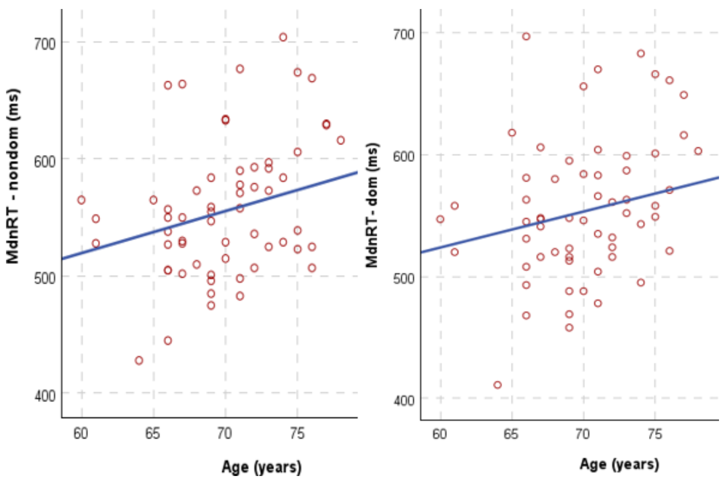
Group / Foot	MdnRT (ms)	iRTSD (ms)	iRTCV% (%)
60–69 years old			
Dominant foot	535.4 ± 57.3	73.6 ± 27.6	13.8 ± 5.2
Non-dominant foot	531.4 ± 49.0	73.2 ± 53.2	13.7 ± 9.5
70–79 years old			
Dominant foot	583.1 ± 95.1	81.3 ± 36.0	13.9 ± 5.8
Non-dominant foot	582.4 ± 93.0	88.0 ± 45.6	14.7 ± 6.1

Note. MdnRT = median of reaction times; iRTSD = intraindividual standard deviation of reaction times; IRTCV% = intraindividual coefficient of variance for reaction times as percentage.

Discussion

The results of the study showed a progressive slowing of simple visuomotor reaction with the lower limbs in women during the 7th and 8th decades of life. A simple reaction task was used in our study. According to the theory of neurocognitive information processing (Schmidt et al., 2011), SRT reflects the duration of stimulus detection and motor response programming, including the conduction of neural commands to the muscles and the electromechanical delay of muscle contractions. Our study thus shows that in women over 60 years of age, there may be a gradual slowing in the detection of visual stimuli and/or deterioration of coupling of this visual detection with the programming of motor responses with the lower limbs. It can be assumed that the deterioration of the integration of these sensorimotor processes correlates with RT (Azim & Kazuhiko, 2019). The interpretation of our results is supported by findings by Hardwick et al. (2022). They reported that age-related increases in RT in healthy older adults resulted from their impaired ability to process stimuli and prepare movements accordingly, not hesitancy to respond. In addition, the sensory specificity of the SSEFR should be considered. Aside from the demand for visual information processing, a sidestep response performed while standing may also reflect vestibular and proprioceptive sensations required to adjust body position for its stabilization (Macpherson & Horak, 2013). These co-occurring sensations could at least partly interact with or disturb visual and motor processing during a response.

Figure 1 Linear regression for median of reaction times measured with the sidestep simple eye-foot reaction test performed with a dominant and non-dominant foot, and the age



Note. MdnRT-dom, MdnRT-nondom = median of intraindividual reaction times achieved with a dominant and non-dominant foot, respectively.

Comparing age-related changes in lower limb RT to hand RT in older age is challenging due to the use of different reaction task protocols, sampling methodologies, outlier identification methods, and RT analysis approaches. Blomkvist et al. (2017) measured lower and upper limb RTs in very similar conditions, where individuals responded to a visual stimulus by touching a board placed in front of the body with their foot or the same board with their hand. Lower limb RT in women increased from the third decade of life (20–29 years) to the ninth decade (80–89 years), while upper limb RT only increased from the fifth decade (40–49 years). Our study shows a progressive prolongation of SRT after 60 years of age, similar to the findings of Blomkvist et al. (2017). However, their reaction test involved a choice RT task, where individuals had to respond with either the right or left foot or hand depending on the side of the board where the visual stimulus appeared.

Previous studies have reported visual SRT of upper limbs in individuals over 60 years of age, typically by pressing a button, to range between 250 and 500 ms (Dykiert et al., 2012; Marusic et al., 2022; Sparrow et al., 2006). In our study, older women aged ≥ 60 achieved sidestep RT averaging 540 and 574 ms. Ashok et al. (2016) found an average brake pedal SRT of 731 ms in individuals over 55 years old. In contrast, Marusic et al. (2022) reported foot RT to visual stimuli averaging only 274 ms in older individuals with a mean age of 67 years. These shorter foot RTs may have been due to responding by pressing a response pad with the foot while resting on the pad between responses. Such a motor response is less complex from a neurophysiological perspective than the sidestep response over a measuring device bar in our study. It is assumed that more complex motor responses prolong RT (Schmidt et al., 2011). Also Marusic et al. (2022) found older individuals to exhibit longer RT with foot response compared to button pressing with the hand (mean SRT 274 ms vs. 255 ms). Although RT can be influenced by various factors, including the nature of the reaction task (Schmidt et al., 2011), the comparisons above support the hypothesis that lower limb response is longer than hand response in older individuals.

While mean SRT is considered a measure of sensory-motor processing rate (Schmidt et al., 2011) and a predictor of overall attentional alertness (Azim & Kazuhiko, 2019), intraindividual variability of RT (across trials) is thought to reflect neurobiological disturbances (Bunce et al., 2017), specifically fluctuations in attentional or executive control (West et al., 2002). There is a general belief that intraindividual RT variability increases with aging (Dykiert et al., 2012; Hultsch et al., 2002). In our study, we did not find age-related changes in intraindividual foot RT variability in women across the period from 60 to 79 years. The authors of this study are aware of only one other study on eye-foot RT variability in an SRT task, conducted by Marusic et al. (2022). These authors found significantly higher foot RT variability in a sample of older individuals with a mean age of 67 years compared to younger adults (34 years). According to the available data in that study, the coefficient of variation of RTs was approximately 16.4% vs. 12.8%, which corresponds to the variability observed in our sample of women (12.5%). Using an eye-hand visual SRT task, Hultsch et al. (2002) showed stepwise impairment in RT variability from 18 to 94 years, specifically when comparing the mild-old group (65–74 years) to the young-old (54–64 years) and the old-old group (75–94 years) to the mild-old group. On the other hand, Dykiert et al. (2012) found an increase in simple visual RTSD in females between 57–67 years but not in older age over 67 years.

One possible explanation for the non-significant age-related increase in RT variability in our study could be that our sample included relatively healthy women with an interest in social activities, as they participated in a senior day event, similar to the samples in Dykiert et al. (2012), who were visitors to a festival. More importantly, our study suggests that, unlike the simple finger button press response, the latency of the more complex neuromuscular foot response (sidestep) may remain stable after the age of 60. The consistency of cognitive performance in our sample of older women is also indicated by fewer than one RT > 1000 ms per person and an average of 1.5 early reactions (mode = 1) out of 48 trials. These findings may indicate infrequent lapses in attention. It is possible that the more complex neuromuscular action, like foot sidestep, may have been associated with increased attention and/or stimulated a strategy to avoid incorrect responses. Vallesi et al. (2021) found that older adults actually outperformed younger adults by producing fewer false alarms in tasks that produce a tendency for automatic responding (go-no-go tasks), suggesting a more prudent strategy when using attentional resources in aging.

Our study also showed that foot response latency and its variability did not depend on the functional laterality of lower limbs, similar to the findings of Blomkvist et al. (2017) in individuals aged 20–90 years. In our sample, we identified 89.4% right-footed and 10.6% left-footed women. This proportion of left-footed individuals corresponds to the 8%–15% reported in a meta-analysis by Packheiser et al. (2020). Some studies, however, report a higher proportion of mixed-footers, up to 30.2% (Tran & Voracek, 2016). A trend toward a significantly higher proportion of mixed-footers than mixed-handers is observed from childhood to adulthood (Gabbard & Iteya, 1996). Mixed-footedness may indicate less clear functional lateralization compared to the upper limbs and a more specific preference related to a specific motor task.

The findings of this study pertain to age-related changes in simple eye-foot RT in relatively healthy women aged 60–79 years. In analyzing the relationship between age and RT, we did not examine other potential moderator variables such as lifestyle, psychosocial influences, education, current physical activity, or overall cognitive and physical fitness. On the other hand, we used a reliable SSEFR test. The inter-item reliability of the SSEFR showed very high reliability (r = .863). We calculated this r as the average of Pearson's correlations between the mean RT of each pair of four blocks of trials (see Methods). This finding suggests that the SSEFR test measured the same construct consistently across all blocks, with a mean random error of 25.3 ms.

Study limitations: Participants were recruited at the "Day for Health", which may have led to the inclusion of relatively healthy, socially active women. This selection limited a broader women population, particularly those with poorer health status or lower levels of physical activity. The sidestep SSEFR task, while physiologically relevant, may not fully capture the complexity of real-world situations requiring rapid lower-limb reactions, e.g., unpredictable falls, driving under cognitive load, and multimodal sensory input. Including only women increases internal consistency but simultaneously limits generalizability to men and precludes examining sex-specific trajectories of visuomotor aging.

Conclusions

To our knowledge, this is among the first studies to investigate trends in cognitive decline in lower limb response latency in women over 60 years. The study showed that during the seventh and eighth decades of life in women, there is a gradual prolongation of lower limb response time, while neurobiological fluctuations manifested by reaction time variability appear to remain stable with age. The functional lateralization of the lower limbs does not appear to influence the speed of motor responses to visual stimuli. In the context of prolonging working life in European countries today, it is necessary to respect the natural aging of cognitive functions when organizing the work environment.

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Conflict of interest

The authors report no conflict of interest.

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