The relationship between spatio-temporal gait parameters and cognition: Results from a cross-sectional study

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Abstract
There is growing evidence of a relationship between gait parameters and cognitive abilities in the elderly. The aim of this study was to investigate the relationship between gait speed and its variability under single-task (ST) and dual-task conditions (DT) and Montreal Cognitive Assessment (MoCA) test scores. The sample included 114 subjects from Slovenia aged 60 and above (age: 66.63 ± 5.16 years; height: 166.29 ± 8.81 cm; mass: 74.91 ± 12.72 kg) of both sexes (60.5 % women). The MoCA test was used to assess cognitive abilities and the Optogait® optical system was used to measure spatio-temporal gait parameters. Significantly lower gait speed ($p < 0.001$) and higher coefficient of variance (CV) of gait speed ($p < 0.001$) were found during DT compared to ST conditions. However, no significant differences were found between individuals with high and low MoCA scores in gait speed ($p = 0.119$) and CV of gait speed ($p = 0.111$) under ST, as well as in gait speed ($p = 0.153$) and CV of gait speed ($p = 0.477$) under DT conditions. Multiple linear regression with stepwise method showed that gait speed in ST conditions was the only significant predictor of final MoCA score ($R^2 = 0.049$; $p = 0.017$). In conclusion, these results suggest that there is an association between gait speed and general cognitive ability, although the proportion of variance explained is small, which we attribute to the limitations of our study (relatively young older adults without severe cognitive impairment). Future studies should provide normative MoCA scores for the Slovenian population and look for correlations between specific MoCA sub-scores that might show higher association, especially with executive functions. Key words: cognitive abilities, gait, MoCA test

Povezava med časovno-prostorskimi parametri hoje in kognicijo: Rezultatni presečne analize

Povzetek
Vse več je dokazov, da obstajajo povezave med hojo in kognitivnimi sposobnostmi pri starejših. Z našo raziskavo smo želeli ugotoviti, ali obstaja povezava med hitrostjo hoje in rezultati Montrealske lestvice spoznavnih sposobnosti (MoCA) med enostavno in kompleksno hojo. V vzorec je bilo vključenih 114 Slovencev obeh spolov (60,5 % žensk), starejših od 60 let (starost: 66,63 ± 5,16 let; višina: 166,29 ± 8,81 cm; teža: 74,91 ± 12,72 kg). Za oceno kognitivnih sposobnosti smo uporabili MoCA test, medtem ko smo z optičnim sistemom Optogait® merili časovno-prostorske parametre hoje. Rezultati so pokazali, da prihaja do značilno nižje hitrosti hoje ($p < 0,001$) in višjega koeficienta variance (CV) hitrosti hoje ($p < 0,001$) med hojo z dodatno kognitivno nalogo (KN) v primerjavi s hojo brez KN. Značilnih razlik ni bilo mogoče potrditi med posamezniki z visokimi in nizkimi rezultati MoCA testa v hitrosti hoje ($p = 0,119$) in CV hitrosti hoje ($p = 0,111$) med hojo brez KN, niti v hitrosti hoje ($p = 0,153$) in CV hitrosti hoje ($p = 0,477$) med hojo z dodatno KN. Večkratna linearna regresija s »stepwise« metodo je pokazala, da je bila hitrost hoje med hojo brez dodatne KN edini pomemben napovedovalec rezultata MoCA testa ($R^2 = 0,049$, $p = 0,117$). Ugotovili smo, da obstaja statistično značilna pozitivna korelacija med hitrostjo hoje brez KN in rezultati testa MoCA, vendar razloži le manjši del variance. Rezultati naše raziskave se ne ujemajo popolnoma s predhodnimi raziskavami, kar pripisujemo omejitvam naše študije (relativno mladi merjenci brez hudega kognitivnega upada). Prihodnje raziskave bi morale postaviti normativne vrednosti MoCA testa za slovensko populacijo in poiskati korelacije med specifičnimi področji MoCA testa, ki bi lahko pokazale večjo povezanost, zlasti z izvršilnimi funkcijami. Ključne besede: kognitivne sposobnosti, MoCA test, hoja

1. INTRODUCTION

Aging brings changes to the body at the physiological level, which is reflected in the deterioration of the functioning of various organ systems and increased susceptibility of the organism to diseases (Navaratnarajah and Jackson, 2013). These changes affect not only the health status (Poredoš, 2004), but also the ability to perform activities of daily living, and thus independence (Chodzko-Zajko et al., 2009).

Two important areas of age-related deterioration are cognitive abilities and gait (Montero-Odasso et al., 2012). Changes in cognitive abilities are associated with changes in the central nervous system (Harada et al., 2013). On the other hand, changes in gait pattern might be related to pathologies of different etiologies or simply to age-related changes in different organ systems, such as loss of muscle mass, hearing or visual impairment (Lippert, 2011). A close relationship between cognition and mobility has been established, particularly in older adults (Marusic et al., 2018), and it is now known that higher-order cognitive processes also play a role in walking (Hausdorff et al., 2005).

Recent studies demonstrated the correlation between cognition and mobility impairments (Buchman et al., 2011). Cognitive impairment was also correlated with an increased risk of falls among the elderly (Anstey et al., 2006; Muir et al., 2012). Better mobility and increased gait speed are associated with a faster processing speed and better executive function (Demnitz et al., 2017). Moreover, Callisaya et al. (2015) found a significant correlation between a decline in executive function and slower gait speed. Many studies have applied dual-task (DT) paradigm to assess the correlation between cognitive abilities and gait parameters (Montero-Odasso et al., 2009; Ijmker and Lamoth, 2012), in which patients are asked to walk and perform another task at the same time (Marusic et al., 2015; Mirelman et al., 2018). Typically, gait parameters deteriorate during dual-tasking. This deterioration is called dual-task cost (Lindenberger et al., 2000; Marusic et al., 2015). Dual-task cost is associated with deterioration in executive function and working memory in people with mild cognitive impairment (Montero-Odasso et al., 2009). In older adults with dementia compared to healthy older adults, Ijmker and Lamoth (2012) confirmed a significantly lower walking speed, a longer mean stride time and a higher stride time variability in DT conditions.

Therefore, the aim of the present study was to investigate the relationship between selected spatio-temporal gait parameters and general cognition in Slovenian older adults of both sexes. Since we selected a relatively active and healthy sample without major cognitive impairments, we assumed that the association between mobility parameters and cognition would be lower. We extended our interest to a DT condition in which attention resources had to be divided between gait control and mental arithmetic.

2. METHODS

Subjects

A cross-sectional study was conducted to investigate the relationship between cognitive abilities and spatio-temporal gait parameters in single-task (ST) and DT conditions. The present study included 114 subjects with a mean age of 66.63 ± 5.16 years. The sample consisted of 69 women (60.5 %) and 45 men (39.5 %), who reached an average of 26.7 ± 2.5 points on MoCA test. The average height of the sample was 166.29 ± 8.81 cm and the average mass was 74.91 ± 12.72 kg. The subjects were informed of the course of the study and signed a written consensus on voluntary participation in the measurements conducted within the international project "*PANGeA – Physical activity and nutrition for quality aging*", supported by a Grant Cross-Border Cooperation Program Slovenia, Italy 2007–2013, Grant Number 042–2/2009. Measurements were performed in DSO Fužine, Ljubljana, Slovenia in 2013. The inclusion criteria were age 60 and above, body mass index (BMI) between 20 and 28 kg/m^2, *Short Physical Performance Battery (SPPB)* result 9 or above, absence of neuro-muscular or cardiovascular diseases and an independently walked distance of at least 2 km. The exclusion criteria were acute and chronic neuro-muscular or cardiovascular diseases, cancer, diabetes, implants, kidney diseases, hypothyroidism, frequent diarrhea or vomiting. The measurements were carried out in accordance with

the WMA Declaration of Helsinki - Ethical Principles for Medical Research Involving Human Subjects. In addition, the measurements were previously approved by the National Medical Ethics Committee of the Republic of Slovenia. The protection of personal data has been ensured according to the Article 24 of the Personal Data Protection Act, ZVOP-1 (Official Gazette of the Republic of Slovenia, No. 86/04) and the General Data Protection Regulation (GDPR - Regulation (EU) 2016/2679 of the European Parliament and of the European Council). The data were anonymized and used for research and publishing purposes only.

Data Acquisition

The Montreal Cognitive Assessment (MoCA) (Nasreddine et al., 2005) was used to assess cognitive abilities. The test assesses: short-term memory, visuospatial abilities, executive functions, attention, concentration and working memory, language and orientation in time and space. The total is 30 points. If the sum of points is less than 26, it is interpreted as a cognitive decline. The scale has high reliability, good specificity, and high sensitivity (Nasreddine et al., 2005). A suitable place in a quiet environment was provided to perform the MoCA test and was conducted individually for each subject. For each task the subject received detailed instructions. The time frame for conducting the MoCA test was about 15 minutes.

The Optogait® optical system (Microgate Corporation, Bolzano, Italy) and the Optogait® software (version 1.9.7.0, Microgate Corporation, Bolzano, Italy) were used to assess spatio-temporal gait parameters. The system consists of 10 transmitting bars and 10 receiving bars that communicate signals via 96 LEDs in the infrared frequency range with a data capture frequency of 1000 Hz and a spatial resolution of 1,041 cm. The bars were placed in parallel at approximately two meters in width and 10 meters in length on a flat surface. High validity of the Optogait® optical system for the assessment of the spatio-temporal gait parameters in older adults has been confirmed (Lienhard et al., 2013). Each subject's spatio-temporal gait parameters were assessed twice; in ST and DT conditions. Prior to initiation, the subjects were given uniform and precise instructions and it was made sure they understood them. In ST conditions the subjects walked at a self-selected speed. In DT conditions subjects had to subtract the number three from a randomly selected number between 400 and 500 out loud. During subtracting, the subjects were not allowed to stop walking. In addition, the examiners recorded the number of correct and incorrect answers. Each measurement lasted approximately 1 minute and 30 seconds at a 10 meters distance. The first bar of the Optogait® optical system was placed approximately 30 cm forms the starting point. After the measurements with Optogait® optical system were completed, the data were reviewed and any errors that occurred in the data capture were manually corrected. The first and the last two steps were ruled out due to acceleration at the beginning and deceleration at the end of the measured distance.

Data Analysis

The data were edited in Microsoft Office Excel 2016 (Microsoft Corporation, New York, USA) and exported for statistical analysis to IBM SPSS Statistics for Windows 25.0 (IBM Corporation, Armonk, New York, USA). Descriptive statistics were given as count (with percentage) or mean (with standard deviation) and minimum and maximum. Normal distribution of all parameters was tested using the Shapiro-Wilk test. To determine the differences between spatio-temporal gait parameters in ST and DT conditions the Wilcoxon signed-rank test was used, while to determine the differences in spatio-temporal gait parameters depending on MoCA scores, the Mann-Whitney U test was used. The Spearman correlation coefficient was used to determine data correlation. A further multiple linear regression with "stepwise" method was conducted for modeling the best prediction of cognitive outcomes through a set of selected spatio-temporal gait parameters. Statistical significance was set at $p\text{-value} < 0.05$ (two-tailed).

3. RESULTS

The Shapiro-Wilk test showed that all parameters significantly deviated from normal distribution ($p < 0.05$). Therefore, the non-parametric statistics was used for further data analysis.
The Wilcoxon's signed-rank test (Table 1) showed that gait speed in DT conditions was significantly lower (by -0.33 ± 0.26 m/s), compared to ST conditions ($p < 0.001$). In addition, the coefficient of variation (CV) of gait speed in DT conditions was significantly higher (by 4.95 ± 8.09 %), compared to ST conditions ($p < 0.001$).

Table *1*: Wilcoxon signed rank test of gait speed and CV of gait speed in ST and DT conditions

	ST		DT		p - value
	M	SD	M	SD	
Gait speed (m/s)	1.34	0.22	1.02	0.28	**< 0.001**
Gait speed CV (%)	5.96	5.09	10.91	6.65	**< 0.001**

Legend: M = mean, SD = standard deviation, CV = coefficient of variance, ST = single-task, DT = dual-task

When investigating the differences between individuals with lower and higher MoCA scores in gait speed and CV of gait speed in both ST and DT conditions (Table 2), on average, a higher gait speed and lower CV of speed was found in individuals with higher MoCA test results, which however did not reach a significance level ($p \geq 0.111$).

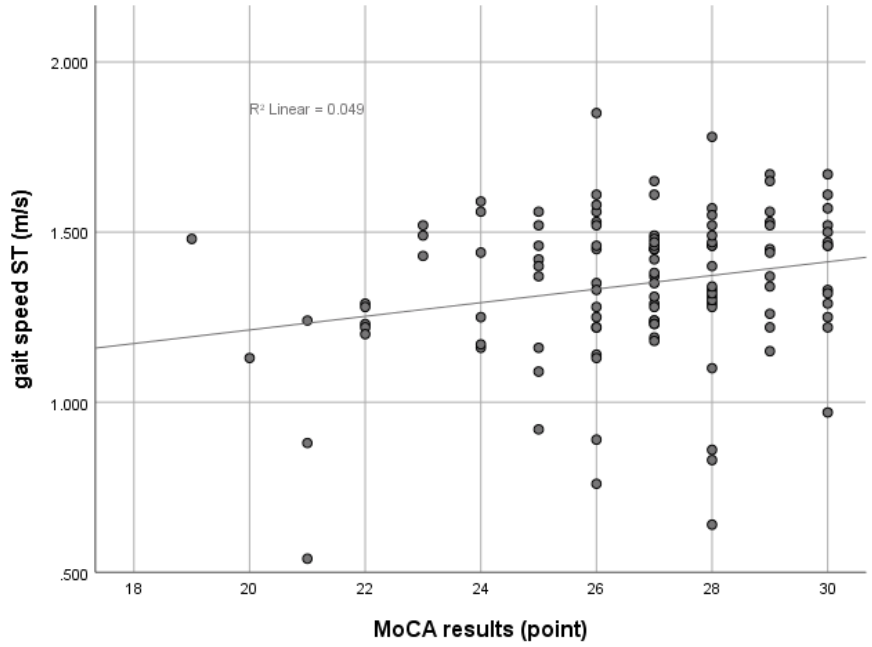
Table *2*: Mann-Whitney U test for gait speed and CV of gait speed in ST and DT conditions according to MoCA test results

	MoCA < 26 N = 28		MoCA ≥ 26 N = 87		p – value
	M	SD	M	SD	
ST Gait speed (m/s)	1.31	0.25	1.37	0.20	0.119
ST Gait speed CV (%)	6.66	5.39	5.48	4.85	0.111
DT Gait speed (m/s)	0.98	0.24	1.04	0.30	0.153
DT Gait speed CV (%)	11.25	6.51	10.69	6.78	0.477

Legend: N = number, M = mean, SD = standard deviation, CV = coefficient of variance, ST = single-task, DT = dual-task

On the other hand, the Spearman correlation showed a significant positive correlation between MoCA scores and gait speed in ST conditions ($r = 0.204$; $p = 0.029$; Figure 1). We could not find significant correlation between MoCA results and gait speed in DT conditions ($r = 0.108$; $p = 0.251$) and between MoCA results and CV of gait speed in ST ($r = -0.148$; $p = 0.116$) and DT conditions ($r = -0.094$; $p = 0.319$). A forward multiple linear regression with "stepwise" method was used to identify possible predictors of the MoCA test outcome. A significant multivariate correlation was found between MoCA test results and gait speed in ST conditions ($R^2 = 0.049$; $p = 0.017$). The explained variance of MoCA test on gait speed in ST conditions was 4.9 %.

Figure 1: Spearman's bivariate correlation between gait speed in ST conditions and MoCA test results



Legend: ST = single-task, MoCA = Montreal Cognitive Assessment

4. DISCUSSION

The present cross-sectional study was conducted to investigate the relationship between cognitive abilities and gait speed in ST and DT conditions in healthy older adults. The results of our study showed that gait speed decreased and became more variable under DT compared to ST. Slower gait speed and higher variability of gait speed under both ST and DT conditions were also found in individuals with lower MoCA test scores. However, no significant difference was found between the two MoCA test score sub-groups. Finally, gait speed in the ST condition was identified as a significant predictor of the MoCA test score. However, the proportion of variance explained was small, explaining only 4.9 % of the variance.
Growing evidence suggests that cognitive and mobility decline are interrelated phenomena which occur in a concurrent manner (Montero-Odasso et al., 2012). On the one hand, cognitive impairment is associated with impaired mobility (Demnitz et al., 2017) and an increased risk of falls in older adults (Anstey et al., 2006; Herman et al., 2010; Muir et al., 2012). On the other hand, cognitive training can improve walking (Marušič and Grosprêtre, 2018) and walking in complex conditions, such as dual-tasking (Marušič et al., 2018). In general, the decrease in gait speed is a physiological change that occurs with aging even in absence of any pathology (Lim et al., 2007; Lippert, 2011). Besides this, gait speed decreases (van Iersel et al., 2008; Montero-Odasso et al., 2009) and the variability of gait speed, stride length and stride width (Callisaya et al., 2010) increases in DT conditions when compared to ST conditions in older adults. Most studies found an increase in stride variability during DT conditions compared to ST conditions (Hollman et al., 2004; an Iersel et al., 2008; de Cassia Gomes et al., 2016). However, Yeo (2017) not only reported increment in variability of stride time but also an increment in stride velocity during working memory DT conditions. In this study we have also found a decrease in gait speed and an increase in its variability during DT compared to ST conditions, which is in accordance with similar studies in this field.
Moreover, studies performed by Gravett (2017) and Hunter et al. (2018) show that individuals with mild cognitive impairment (MCI), assessed by Mini-Mental State Exam, show lower gait speed in ST and DT conditions compared to healthy controls. However, the results of our study do not support previous

research in this segment. Furthermore, Choir et al. (2019) demonstrated a significant positive correlation between gait speed and MoCA test scores in patients with MCI as well as in those with Alzheimer dementia. Similarly, Lønseth (2016) found a positive correlation between gait speed and MoCA test scores in older adults (70–76 years of age) with relatively intact cognition (MoCA score = 25.87 ± 3.27 points) during ST and DT conditions. In addition, gait speed was found to be a significant predictor of follow-up cognition at a checkup after 2 years in the study of Ojagbemi et al. (2015). Thus, while some of the results in our study do not coincide with previous research, based on the reviewed literature, it can be supposed with relatively high probability that cognitive functions positively correlate with gait parameters (especially gait speed) during ST as well as during DT conditions.

Some potential limitations of the present study need to be considered. Firstly, our study has only considered gait speed and CV of gait speed. Therefore, there are many other spatio-temporal parameters to be verified in the future analysis. Secondly, the obtained results cannot be generalized to the entire older adult population as the study has only included individuals aged 60–79 years with specific inclusion/exclusion criteria, which resulted in subjects which had good functional abilities and were independent in daily living activities. In addition, the distribution in the sample was uneven: 48 subjects (41.7%) aged between 60 and 64 years, 36 subjects (31.3%) aged between 65 and 69 years, 18 subjects (15.7 %) aged between 70 and 74 years and 13 subjects (11.3%) aged over 75 years. Thirdly, individuals included in the study had relatively intact cognition. The mean of MoCA test was 26.67 ± 2.45 points. Moreover, the distribution according to MoCA test scores was uneven: 28 subjects (24.3 %) with MoCA results 25 or less and 87 subjects (75.7 %) with MoCA results 26 or more. In order to generalize the obtained results, future studies should provide normative MoCA scores for the Slovenian population and look for correlations between specific MoCA sub-scores that might show higher association, especially with executive functions.

5. CONCLUSION

In conclusion, these results suggest there is an association between gait speed and general cognitive ability, although the proportion of variance explained is small, which we attribute to the limitations of our study. Given the limitations, further research is needed on this matter to generalize the obtained results.

6. ACKNOWLEDGMENTS

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7. REFERENCES

1. *Anstey K J, Von Sanden C, Luszcz M A, An 8-Year Prospective Study of the Relationship Between Cognitive Performance and Falling in Very Old Adults. J Am Geriatr Soc, 2006, 54: 1169–1176, doi: 10.1111/j.1532-5415.2006.00813.x*
2. *Buchman A S, Boyle P A, Leurgans S E et al., Cognitive Function is Associated with the Development of Mobility Impairments in Community-Dwelling Elders. Am J Geriatr Psychiatry, 2011, 19: 571-580, doi: 10.1097/JGP.0b013e3181ef7a2e.*
3. *Callisaya M L, Blizzard C L, Schmidt M D et al., Ageing and gait variability—a population-based study of older people. Age Ageing, 2010, 39: 191–197, doi: 10.1093/ageing/afp250*

4. *Callisaya M L, Blizzard C L, Wood A G et al., Longitudinal Relationships Between Cognitive Decline and Gait Slowing: The Tasmanian Study of Cognition and Gait. J Gerontol A Biol Sci Med Sci, 2015, 70: 1226–1232, doi: 10.1093/gerona/glv066*
5. *Chodzko-Zajko W J, Proctor D N, Fiatarone Singh M A et al., Exercise and Physical Activity for Older Adults. Med Sci Sports Exerc, 2009, 41: 1510–1530, doi: 10.1249/MSS.0b013e3181a0c95c.*
6. *Choi J, Park J, Lee B et al., The Correlation between Cognition Screening Scores and Gait Status from Three-Dimensional Gait Analysis. J Clin Neurol, 2019, 15: 152–158. doi: 10.3988/jcn.2019.15.2.152.*
7. *de Cássia Gomes G, Teixeira-Salmela L F, Silveira de Freitas F A et al., Gait performance of the elderly under dual-task conditions: Review of instruments employed and kinematic parameters. Rev. bras. geriatr. gerontol., 2016, 19: 165–182, https://doi.org/10.1590/1809-9823.2016.14159.*
8. *Demnitz N, Zsoldos E, Mahmood A et al., Associations between Mobility, Cognition, and Brain Structure in Healthy Older Adults. Front Aging Neurosci, 2009, doi: 10.3389/fnagi.2017.00155.*
9. *Gravett S, Gait and Mild Cognitive Impairment: How spatiotemporal parameters and gait variability are affected in MCI (Master's Thesis). Umeå University: Faculty of Social Sciences, Department of Psychology, 2017.*
10. *Harada C N, Natelson Love M C, Triebel K L, Normal cognitive aging. Clin Geriatr Med, 2013, 29: 737–752, doi: 10.1016/j.cger.2013.07.002.*
11. *Hausdorff J M, Yogev G, Springer S et al., Walking Is More Like Catching Than Tapping: Gait in the Elderly as a Complex Cognitive Task. Exp Brain Res, 2005, 164: 541–548, doi: 10.1007/s00221-005-2280-3.*
12. *Herman T, Mirelman A, Giladi N et al., Executive Control Deficits as a Prodrome to Falls in Healthy Older Adults: A Prospective Study Linking Thinking, Walking, and Falling. J Gerontol A Biol Sci Med Sci, 2010, (10): 1086–1092, doi: 10.1093/gerona/glq077.*
13. *Hollman J H, Salamon K B, Priest A, Age-Related Differences in Stride-to-Stride Variability During Dual Task Walking: A Pilot Study. J Geriatr Phys Ther, 2004, 27: 83–87, doi: 10.1519/00139143-200412000-00002.*
14. *Hunter S W, Divine A, Frengopoulos C et al., A framework for secondary cognitive and motor tasks in dual-task gait testing in people with mild cognitive impairment. BMC Geriatr, 2018, 18: 202, https://doi.org/10.1186/s12877-018-0894-0.*
15. *Ijmker T, Lamoth C J C, Gait and cognition: The relationship between gait stability and variability with executive function in persons with and without dementia. Gait Posture, 2012, 35: 126–130, doi: 10.1016/j.gaitpost.2011.08.022.*
16. *Lienhard K, Schneider D, Maffiuletti N A, Validity of the Optogait photoelectric system for the assesment of spatiotemporal gait parameters. Med Eng Phys, 2012, 34: 500–504, doi: 10.1016/j.medengphy.2012.06.015.*
17. *Lim M R, Huang R C, Wu A et al., Evaluation of the Elderly Patient With an Abnormal Gait. J Am Acad Orthop Surg, 2007, 15: 107–117, doi: 10.5435/00124635-200702000-00005.*
18. *Lindenberger U, Marsiske M, Baltes P B, Memorizing While Walking: Increase in Dual-Task Costs From Young Adulthood to Old Age. Psychol Aging, 2000, 15: 417–436, doi: 10.1037//0882-7974.15.3.417.*
19. Lippert L S, Clinical Kinesiology and Anatomy, Fifth edition. USA: F. A. Davis Company, 2011.
20. Lønseth A, The association between gait and cognitive function in relatively healthy elderly people (Master's thesis). Norwegian University of Science and Technology: Faculty of Medicine, Department of Neuroscience, 2016.
21. *Marušič U, Kavčič V, Giordani B, et al., Computerized spatial navigation training during 14 days of bed rest in healthy older adult men: Effect on gait performance. Psychol Aging, 2015, 30: 334–340, doi: 10.1037/pag0000021.*
22. *Marušič U, Grosprêtre S, Non-physical approaches to counteract age-related functional deterioration: Applications for rehabilitation and neural mechanisms. Eur J Sport Sci, 2018, 18: 639–649, doi: 10.1080/17461391.2018.1447018.*

23. *Marušič U, Verghese J, Mahoney J R, Cognitive-Based Iterventions to Improve Mobility: A Systematic Review and Meta-anaylsis. J Am Med Dir Assoc, 2018, 19: 484–491, doi: 10.1016/j.jamda.2018.02.002.*
24. *Mirelman A, Shema S, Maidan I, et al., Gait. Handb Clin Neurol, 2018, 159:119–134, doi: 10.1016/B978-0-444-63916-5.00007-0.*
25. *Montero-Odasso M, Bergman H, Phillips N A et al., Dual-tasking and Gait in People With Mild Cognitive Impairment. The Effect of Working Memory. BMC Geriatr, 9: 41, doi: https://doi.org/10.1186/1471-2318-9-41.*
26. *Montero-Odasso M, Verghese J, Beauchet O et al., Gait and Cognition: A Complementary Approach to Understanding Brain Function and the Risk of Falling. J Am Geriatr Soc, 2012, 60: 2127–2136, doi: 10.1111/j.1532-5415.2012.04209.x.*
27. *Muir S W, Gopaul K, Montero-Odasso M M, The role of cognitive impairment in fall risk among older adults: a systematic review and meta-analysis. Age Ageing, 2012, 41: 299–308, doi: 10.1093/ageing/afs012.*
28. *Nasreddine Z S, Phillips N A, Bédirian V et al., The Montreal Cognitive Assessment, MoCA: A Brief Screening Tool for Mild Cognitive Impairment. J Am Geriatr Soc, 2005, 53: 695–699, doi: 10.1111/j.1532-5415.2005.53221.x.*
29. *Navaratnarajah A, Jackson S H D, The physiology of ageing. Medicine 2013, 41: 5–8, doi: 10.1016/j.mpmed.2012.10.009.*
30. *Ojagbemi A, D'Este C, Verdes E et al., Gait speed and cognitive decline over 2 years in the Ibadan study of aging. Gait Posture, 2015, 41 (2): 736–740, doi: 10.1016/j.gaitpost.2015.01.011.*
31. *Poredoš P, Zdravstveni problemi starostnikov. Zdrav Vestn, 2004, 73:753–756.*
32. *van Iersel M B, Kessels R P C, Bloem B R et al., Executive Functions Are Associated With Gait and Balance in Community-Living Elderly People. J Gerontol A Biol Sci Med Sci, 2008 63: 1344–1349, doi: 10.1093/gerona/63.12.1344.*
33. *Yeo S S, Changes of Gait Variability by the Attention Demanding Task in Elderly Adults. J Kor Phys Ther, 2017, 29: 303–306, doi: https://doi.org/10.18857/jkpt.2017.29.6.303.*