Age-related features of walking with cognitive tasks

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Human walking is considered as a complex cognitive act. The research purpose is an analysis of age-related features of spatio-temporal parameters of human walking and directions of their changes at walking with dual (cognitive) tasks. The walking spatio-temporal indexes were studied in 608 individuals of both sexes aged 12-43 years by GAITRite® (CIR Systems Inc., Clifton, NJ) under normal walking at individually comfortable velocity and under additional cognitive tasks: 1) sequentially pronounce aloud any known animals; 2) starting from a number 100, subtract 7 and pronounce the result aloud. The statistical processing of the got results was carried out in the licensed software "STATISTICA 5.5". At performing the first, simpler, task, the spatial parameters had no significant changes in all age groups. Most of the temporal parameters changed: cycle time, swing time, single support time, and double support time increased. Therefore, equilibrium maintaining at walking with naming animals is realized with a longer overall support period, reducing the walking cadence and velocity. The constant width of the support base and the angle of the feet turn indicate that the magnitudes of the functional support base and angle of the feet turn at normal walking is sufficient to maintain posture and balance at walking with simultaneous performance of the cognitive task, as well as more rigid mechanisms of regulation of these two parameters. The walking temporal parameters are more labile than spatial parameters. With age, the percentage of the integral index of walking quality (FAP) decreases especially in females: in girls by 15.3 %, in young women by 14.4 %, in middle-aged women by 7.4 %. At performing the second, more complex, arithmetic task, in young men and young girls support base, toe-in-out, step length difference had no significant changes only. The mean velocity, cadence, step length, stride length, step extremity ratio decreased. The count of steps, all temporal parameters, and stance percentage increased. FAP declined critically by 30.4 % in young men and 33.4 % in young women, indicating a decrease in balance and body stability under walking with cognitive task and increasing the risk of falls. Therefore, a significant reduction in FAP can be used as a diagnostic criterion in neurological practice.

Keywords: spatial and temporal parameters of walking, different age groups, gait with an additional cognitive task.

Introduction

Human movements consist of maintenance of equilibrium and movement proper (motor component, locomotion). Normal human movements provide not only a movement in space but also satisfaction of everyday necessities, maintenance of full-fledged social relations and life quality. Practically all parts of the central nervous system (CNS) - centers of locomotion, postural control, balance, voluntary movements, cognitive processes contribute to control of upright walking and labour activity [12, 14]. Therefore, a human walking should be considered not only

as a motor, but also as a complex cognitive act [23]. Having analyzed 62 research papers on effect of cognitive tasks on human walking performance in 2300 persons [1], the authors concluded that the use of dual task methodology (walking and cognitive/motor task) has become a leading theme in human walking studies. However, despite the growing body of researches on human walking and its disorders, there remain a number of unsolved issues. They revealed walking disorders while performing additional tasks in the elderly, neurological patients [5, 6, 10]. At the same time, there are

reports of the lack of cognitive tasks effect on walking in both young healthy people and healthy elderly people [19]. But the authors used light cognitive tasks as additional ones that required low cognitive costs, or perhaps priority during research was given exceptionally to walking. In single researches of walking with dual tasks (cognitive/motor) in young healthy people individual indexes were studied only and in most researches without the account of age and gender [11].

Thus, the organization of walking and its disorders remain one of the most difficult sections of physiology and pathology of the nervous system, due not only to the mysterious intimate mechanisms, but also to the methodological problems of the walking research.

The *research purpose* is an analysis of age-related features of spatio-temporal parameters of human walking and directions of their changes at walking with dual (cognitive) tasks.

Materials and methods

608 clinically healthy individuals of both sexes aged 12-43 years were examined. The age distribution was as follows: 69 adolescents - 36 girls (12-15 years) and 33 boys (13-16 years); 502 young people - 241 young men (17-21 years) and 261 young women (16-20 years); 37 middle-aged women (21-43 years). During the study period, the volunteers did not have traumas and diseases that could lead to changes in walking parameters, did not use alcohol, sedatives, and medications for the last 72 hours. The spatio-temporal indexes of walking were studied by the high-quality computerized electronic walkway system GAITRite® (CIR Systems Inc., Clifton, NJ), which is a 4.2 meter long and 1.5 meter wide polymer path with built-in 22000 pressure sensors. While walking along the path, the system scans the sensors, processes them, saves and calculates the integral spatial and temporal parameters of walking. The gait parameters were determined separately for the right and left legs. The study was performed without shoes, as more reliable changes in the spatio-temporal parameters are obtained [22]. The reliability of the GAITRite® system has been established in a number of studies [8, 15, 20, 27]. The followings parameters were determined: velocity, step count, cadence, step length, stride length, step length difference, support base, step time, cycle time, swing time, single support time, double support time, structure of step cycle, integral index of walking quality - Functional Ambulation Performance Score, FAP. The integral index of general walking quality ("normality" of walking) FAP represents the level of maintenance of equilibrium and stability of body during movement. FAP is represented as a singular number and automatically calculated by the GAITRite® system, taking into account step time, step extremity ratio, mean normalized velocity (velocity/mean extremity length) and mean extremity length - the arithmetic mean of the right and left extremities length. The magnitude of FAP is also influenced by extraneous assistance, the use of assisted equipment, and

the dynamics of the support base. Normally, the FAP magnitude is 95-100 %. The walking parameters were evaluated under normal walking at individually comfortable velocity and under additional cognitive tasks: 1) sequentially pronounce aloud any known animals without repeating; 2) starting from a number 100, subtract 7 and pronounce the result aloud. The quality of walking and the quality of the cognitive task were evaluated. There was no indication of the priority of one task over another (walking over the cognitive task or vice versa). The results of the automatic calculation of walking parameters were transferred to the "Excel" spreadsheet for further processing, analysis and comparison. The statistical processing of the got results was carried out in "STATISTICA 5.5" (owned by Center of Scientific and Information Technologies of Vinnytsya National Pirogov Memorial Medical University, license number AXXR910A374605FA).

Results

In the researches of walking with pronouncing aloud any known animals 69 adolescents, 298 persons of youth age, 37 women of middle ages were examined.

It was set that in boys, the velocity was 118.6 ± 3.5 cm/s. cadence was 101.8 ± 2.0 steps/min. Spatial parameters were as follows: step length right was 69.41 ± 1.46 cm, step length left - 70.03 ± 1.42 cm; step extremity ratio right 0.771 ± 0.021 and step extremity ratio left 0.781 ± 0.021 ; stride length right 139.34 ± 2.83 cm, stride length left 139.38 ± 2.8 cm; support base right was 10.62 ± 0.59 cm, support base left 10.25 ± 0.58 cm; toe-in-out right was $9.231 \pm 1.041^\circ$, toe-in-out left - $7.401 \pm 1.082^\circ$. Temporal indexes: step time right and step time left were identical 0.602 ± 0.011 s; cycle time right was 1.191 ± 0.032 s, cycle time left - 1.192 ± 0.021 s; swing time right and swing time left were identical 0.502 ± 0.011 s; stance time right and stance time left were identical 0.701 ± 0.022 s; duration of single support was 0.502 ± 0.010 s for both extremities; double support time was identical for both extremities - 0.210 ± 0.010 s. FAP index was 83.15 ± 3.88 %.

At comparing the spatio-temporal parameters of the ordinary walking and walking with simultaneous cognitive task in boys it was revealed that spatial indexes do not have reliable changes ($p > 0.05$). Most temporal parameters differed statistically: step time was increased from both sides (by 11.1 ± 1.9 %), cycle time left - (by 10.2 ± 0.9 %) cycle time right - (by 11.2 ± 0.9 %) ($p < 0.05$), cadence diminished (by 9.3 ± 1.1 %) ($p < 0.001$), single support time was increased from both sides (by 13.6 ± 2.3 %), swing time from both sides (by 13.6 ± 2.3 %) ($p < 0.001$). Stance time was increased from both sides (by 19.4 ± 4.5 %). velocity diminished (by 8.4 ± 2.6 %) and ambulation time was increased (by 9.0 ± 3.8 %) ($p < 0.05$). Time of double support from both sides did not have reliable changes only ($p > 0.05$).

In young men the velocity was 124.11 ± 3.29 cm/s, cadence was 102.09 ± 1.68 steps/min. The following spatial parameters were got: step length right was 72.17 ± 1.21 cm, step length left - 72.98 ± 1.18 cm; step extremity

ratio was identical from both sides and was 0.792 ± 0.011 ; stride length right was 145.57 ± 2.32 cm, stride length left - 144.97 ± 2.20 cm; support base right was 10.48 ± 0.48 cm, support base left - 10.51 ± 0.46 cm; toe-in-out right was $10.36 \pm 0.85^\circ$, toe-in-out left - $7.976 \pm 0.759^\circ$. Temporal indexes: step time right was 0.587 ± 0.012 s, step time left - 0.596 ± 0.010 s; cycle time right was 1.192 ± 0.031 s, cycle time left - 1.188 ± 0.019 s; swing time right and swing time left were identical 0.502 ± 0.009 s; stance time right lasted 0.701 ± 0.010 s, stance time left - 0.693 ± 0.008 s; duration of single support was 0.502 ± 0.011 s from both sides; double support time right and double support time left were - 0.210 ± 0.010 s. FAP index was 82.1 ± 2.2 %.

At comparing the spatio-temporal parameters of the ordinary walking and walking with simultaneous cognitive task in young men it was revealed that spatial indexes do not have reliable changes ($p > 0.05$). Most temporal parameters differed statistically: step time left was increased (by 7.1 ± 1.8 %), step time right was increased (by 7.3 ± 1.8 %), cycle time from both sides was increased (by 7.2 ± 1.8 %) ($p < 0.05$), cadence diminished (by 6.4 ± 0.4 %) ($p < 0.001$), single support time left was increased (by 11.1 ± 2.2 %) single support time right was increased (by 8.7 ± 2.2 %), swing time left was increased (by 8.7 ± 2.2 %) swing time right was increased (by 11.1 ± 2.2 %), ($p < 0.001$), stance time left was increased (by 4.5 ± 1.5 %) stance time right was increased (by 7.7 ± 1.5 %), velocity diminished (by 6.5 ± 2.5 %) and ambulation time was increased (by 5.2 ± 3.7 %) ($p < 0.05$). Time of double support from both sides did not have reliable changes only ($p > 0.05$).

In girls, the velocity was 103.26 ± 4.51 cm/s, cadence was 95.53 ± 2.71 steps/minute. The following spatial parameters were obtained: step length right was 64.01 ± 1.37 cm, step length left - 64.09 ± 1.32 cm; step extremity ratio right was 0.761 ± 0.019 and step extremity ratio left - 0.761 ± 0.009 ; stride length right was 128.33 ± 2.62 cm, stride length left - 128.16 ± 2.67 cm; support base right was 7.101 ± 0.592 cm, support base left - 7.03 ± 0.591 cm; toe-in-out right was $2.511 \pm 0.892^\circ$, toe-in-out left - $0.402 \pm 0.841^\circ$. Temporal indexes: step time right and step time left were identical and equal 0.654 ± 0.021 s; cycle time right and cycle time left were identical and equal 1.302 ± 0.041 s; swing time right was 0.543 ± 0.019 s, swing time left - 0.536 ± 0.020 s; stance time right was 0.768 ± 0.029 s, stance time left - 0.764 ± 0.031 s; single support time right was 0.528 ± 0.021 s and single support time left - 0.543 ± 0.019 s; double support right and double support left were identical - 0.248 ± 0.007 s. FAP index was 81.8 ± 1.8 %.

At comparing the spatio-temporal parameters of the ordinary walking and walking with simultaneous cognitive task in girls it was revealed that spatial indexes do not have significant changes ($p > 0.05$). Most temporal parameters differed statistically: step time was increased (by 20.4 ± 1.9 % from both sides) as well as cycle time (by 20.4 ± 1.9 % from both sides) ($p < 0.05$), single support time left (by 22.7 ± 2.3 %) single support time right (by 20.5 ± 2.3 %), swing

time left (by 20.5 ± 2.3 %) swing time right (by 22.7 ± 2.3 %) ($p < 0.001$), stance time left (by 20.3 ± 3.1 %) stance time right (by 18.6 ± 3.1 %), double support time left (by 19.0 ± 3.1 %) double support time right (by 25.0 ± 5.0 %) ($p < 0.05$), velocity diminished (by 13.0 ± 1.2 %) and ambulation time increased (by 22.4 ± 5.1 %) ($p < 0.05$), cadence diminished (by 14.8 ± 0.8 %) ($p < 0.001$).

In young women velocity was 98.974 ± 3.32 cm/s; cadence was 93.56 ± 2.27 steps per minute. Spatial parameters: step length right was 62.53 ± 0.87 cm, step length left 62.98 ± 0.93 cm; step extremity ratio right was 0.733 ± 0.009 and step extremity ratio left - 0.741 ± 0.011 ; stride length right was 125.7 ± 1.8 cm, stride length left - 125.6 ± 1.8 cm; support base right was 6.619 ± 0.494 cm, support base left - 6.553 ± 0.484 cm; toe-in-out right was $2.952 \pm 0.658^\circ$, toe-in-out left - $0.501 \pm 0.687^\circ$. Temporal parameters: step time right was 0.658 ± 0.017 s, step time left - 0.681 ± 0.020 s; cycle time right was 1.341 ± 0.039 s, cycle time left - 1.337 ± 0.041 s. swing time right was 0.543 ± 0.021 s, swing time left - 0.562 ± 0.020 s, stance time right - 0.788 ± 0.031 s, stance time left - 0.769 ± 0.018 s, single support time right was 0.568 ± 0.021 s and single support time left 0.538 ± 0.019 s. Double support right and double support left were identical - 0.262 ± 0.011 s. FAP index was 82.3 ± 1.1 %.

At comparing the spatio-temporal parameters of the ordinary walking and walking with simultaneous cognitive task in young women it was revealed that spatial indexes do not have significant changes ($p > 0.05$). All temporal parameters were statistically different. It was determined increasing in step time left (by 25.9 ± 1.9 %) and step time right (by 24.5 ± 1.9 %), step cycle left (by 24.3 ± 0.9 %) and step cycle right (by 25.2 ± 0.9 %), single support time left (by 22.7 ± 2.3 %) single support time right (by 27.3 ± 2.3 %), swing time left (by 27.3 ± 2.3 %) and swing time right (22.7 ± 2.3 %) ($p < 0.001$), stance support left (22.2 ± 1.7 %) and stance support right (23.4 ± 1.6 %), double support time from both sides (by 30.0 ± 5.0 %) ($p < 0.05$). Velocity decreased (by 16.1 ± 0.9 %) ($p < 0.001$), ambulation time increased (by 25.0 ± 3.9 %) ($p < 0.05$) and cadence decreased (by 17.4 ± 0.8 %) ($p < 0.001$).

In middle-aged women, velocity was 101.32 ± 4.48 cm/s; the number of steps per minute was 94.24 ± 3.11 . Spatial parameters: step length right was 63.68 ± 1.12 cm, step length left was 63.78 ± 1.07 cm; step extremity ratio right was 0.738 ± 0.018 and step extremity ratio left - 0.751 ± 0.009 ; stride length right was 127.5 ± 2.1 cm; stride length left was 127.9 ± 2.2 cm; support base right was 6.452 ± 0.576 cm, support base left - 6.482 ± 0.568 cm; toe-in-out right was $2.281 \pm 0.802^\circ$, toe-in-out left - $4.148 \pm 0.942^\circ$. Temporal parameters: step time right and left were the same 0.669 ± 0.028 s; cycle time right was 1.342 ± 0.051 s, cycle time left - 1.323 ± 0.048 s; swing time right and left were equal 0.542 ± 0.021 s; stance time right was 0.803 ± 0.038 s, stance time left - 0.792 ± 0.032 s, single support time was 0.538 ± 0.019 s for both sides; double support right and double support left were identical - 0.279 ± 0.018 s. FAP index

was 79.48 ± 4.71 %.

At comparing the spatio-temporal parameters of the ordinary walking and walking with simultaneous cognitive task in middle-aged women it was determined that the spatial parameters had no significant changes ($p > 0.05$). Most of the temporal parameters were statistically different: it was determined increasing in step time on both sides (by 21.8 ± 3.6 %), cycle time left (by 20.0 ± 2.7 %) and cycle time right (by 21.8 ± 2.7 %), single support time on both sides (22.7 ± 2.3 %), swing time on both sides (22.7 ± 2.3 %), stance time left (19.7 ± 3.0 %) and stance time right (19.4 ± 4.5 %) ($p < 0.001$), double support time on both sides (21.3 ± 4.3 %); velocity decreased (9.8 ± 1.5 %), ambulance time increased (by 13.7 ± 4.8 %) ($p < 0.05$) as well as cadence (by 14.2 ± 1.2 %) ($p < 0.001$).

At the age-related comparison of the studied groups, no significant differences in the quality of the cognitive task performance were detected ($p > 0.05$). To analyze the cognitive task quality at walking the average number of errors in absolute quantity and in the percentage of detected errors to the total number of the named animals in each age group were determined. Repetition of an already named animal during walking or complete stop were errors.

Walking with arithmetic cognitive task (starting from a number 100, subtract 7 and pronounce the result aloud) was examined in 204 adolescents.

In young men it was found, that the average walking speed was 61.68 ± 2.77 cm/s; steps number per minute was 61.41 ± 2.43 . Step length of the right leg was 60.23 ± 1.042 cm, of the left leg 60.09 ± 1.09 cm; ratio of stride length to leg length was the same for the right and left legs and was 0.653 ± 0.012 ; the difference between step length of the right and left legs was 2.682 ± 0.248 cm; double step length of the right leg was 120.36 ± 2.11 cm, of the left one was 120.17 ± 2.14 cm; width of the support base for the right leg was 10.06 ± 0.49 cm, for the left - 10.01 ± 0.49 cm; rotation angle of the right foot was $8.232 \pm 0.691^\circ$, of the left - $5.518 \pm 0.672^\circ$. The average length of steps for the right leg was 1.187 ± 0.079 s, for the left one - 1.173 ± 0.068 s; duration of stepping cycle for the right leg was 2.35 ± 0.136 s, the left - 2.368 ± 0.136 s. Duration of the right leg transfer was 0.931 ± 0.062 s, of the left - 0.918 ± 0.057 s; reliance time for the right leg lasted 1.413 ± 0.078 s, for the left one 1.449 ± 0.087 s; duration of single reliance of the right leg was 0.921 ± 0.058 s, of the left one 0.928 ± 0.059 s; time of double reliance while performing a step by the right leg lasted 0.513 ± 0.041 s, by the left - 0.519 ± 0.039 s. The difference in step duration between the right and the left leg was 0.209 ± 0.038 s, and the difference in step cycles duration for both legs was 0.091 ± 0.019 s. In the structure of walking cycle with simultaneous performance of cognitive task in boys, the following ratios were obtained: the duration of foot transfer from the total duration of the walking cycle was 38.9 ± 0.5 % for the right leg, 38.8 ± 0.6 % for the left leg; reliance duration for the right leg was 61.1 ± 0.5 % of the total duration of stepping cycle, for the left leg - 61.2 ± 0.6 %; single reliance

duration of the right leg in examined boys was 39.2 ± 0.6 %, of the left - 38.8 ± 0.7 % of the total duration of the respective step cycle; reliance on both feet for the stepping cycle for the right leg was 22.3 ± 0.8 %, for the left leg - 22.6 ± 0.8 %. FAP of walking with simultaneous performance of cognitive task in adolescent boys was 67.6 ± 1.7 %.

At comparing the spatio-temporal parameters of the ordinary walking and walking with simultaneous cognitive task in young men it was revealed that step length and stride length for both legs, as well as step extremity ratio were significantly smaller at walking with the cognitive task ($p < 0.001$ in all cases). The support base for both legs, toe-in-out and step length difference at walking with the simultaneous performance of the cognitive task remained unchanged ($p > 0.05$). Step time for both legs, cycle time for both legs, stance time for both legs, swing time for both legs, single support time for both legs, and double support time for both legs were statistically significantly higher ($p < 0.001$ in all cases). The step time difference and cycle time difference were increased ($p < 0.001$ in both cases). In the step cycle structure the percentage of swing time right ($p < 0.01$) and swing time left ($p < 0.001$), single support time for each leg were reduced ($p < 0.001$), the percentage of stance time right ($p < 0.001$) and left ($p < 0.001$) as well as double support time were increased ($p < 0.001$).

Thus, among all spatio-temporal parameters in walking with the cognitive task, only the support base for each leg, toe-in-out, step length difference was not significantly different compared to ordinary walking. The velocity, cadence, step length, stride length, step extremity ratio decreased significantly. The number of steps along the GAITRite® mat, as well as all temporal parameters increased significantly. In the step cycle structure the portion of stance time right and left, and double support time were increased, but the portion of swing time right and left, and single support time for each leg were reduced.

The spatio-temporal parameters when walking with simultaneous performance of the same cognitive task in young women were as follows: average speed of movement 47.16 ± 2.38 cm/s; per minute the girls performed 54.38 ± 2.18 steps; the right leg step length was 51.19 ± 0.91 cm, for the left leg 50.58 ± 0.88 cm; ratio of stride length to leg length was the same for the right and left legs and was 0.602 ± 0.009 ; difference between step length of the right and left legs was 2.602 ± 0.201 cm; double step length of the right leg was 101.7 ± 1.8 cm, of the left one was 102.0 ± 1.8 cm; width of the support base for the right leg was 6.209 ± 0.428 cm, for the left leg - 6.138 ± 0.418 cm; the right foot rotation angle was $4.019 \pm 0.621^\circ$, for the left - $0.501 \pm 0.658^\circ$. Right leg steps duration was 1.348 ± 0.068 s, for the left one - 1.279 ± 0.057 s. Stepping cycle duration for the right leg was 2.62 ± 0.127 s, for the left 2.581 ± 0.117 s; duration of the right leg transfer was 1.009 ± 0.058 s, of the left one - 0.948 ± 0.048 s; reliance duration for the right leg was 1.608 ± 0.082 s, for the left one - 1.638 ± 0.079 s; single reliance duration of the right foot was 0.947 ± 0.049 s, of the left one was 1.012 ± 0.058 s;

reliance on both feet when performing a step with the right leg lasted 0.662 ± 0.043 s, left - 0.668 ± 0.044 s; difference in step duration between the right and left legs was 0.212 ± 0.031 s, and the difference in step cycles duration for both legs was 0.139 ± 0.017 s; foot transfer duration from the total duration of stepping cycle was 37.9 ± 0.6 % for the right leg, 36.6 ± 0.6 % for the left leg; reliance duration for the right leg was 62.2 ± 0.6 % of the total duration of stepping cycle, for the left leg it was 63.4 ± 0.6 %; duration of a single reliance for the right leg was 36.5 ± 0.6 % of the total duration of stepping cycle, with the left - 38.1 ± 0.7 %; both feet reliance for stepping cycle for the right leg was 25.7 ± 0.8 %, for the left leg - 26.3 ± 0.9 %. FAP when walking with simultaneous cognitive task in girls was 63.4 ± 1.5 %.

At comparing the spatio-temporal parameters of the ordinary walking and walking with simultaneous cognitive task in young women it was found out statistically significant differences among most spatial and all temporal parameters. The velocity was significantly lower, the cadence was greater, the young women performed significantly fewer steps per minute ($p < 0.001$ in all cases). The step length and stride length, as well as the step extremity ratio were statistically significantly smaller ($p < 0.001$ in all cases). The support base and toe-in-out did not differ ($p > 0.05$), and step length difference significantly increased ($p < 0.001$). Step time, cycle time, swing time, stance time, single support and double support for both legs were statistically significantly greater than when walking ($p < 0.001$ in all cases). The difference in step time and cycle for both legs increased ($p < 0.001$ in both cases). In the step cycle structure, both percentage of swing time for both extremities and percentage of single time for each extremity from the duration of their step cycles ($p < 0.001$) significantly decreased, and percentage of stance time for each leg, double support time right and left increased significantly ($p < 0.001$).

In detailed analysis of actual cognitive task quality, it was found that standing in the general group of adolescents, out of 14 possible numbers to calculate, the average number of errors for them was 1.1 ± 1.4 , which is equal to 7.9 ± 9.8 %.

When performing a cognitive task while walking on a track in adolescents group, the average total number of calculated numbers was 8.3 ± 3.2 , and the average number of errors in calculations - 1.3 ± 1.5 , which is equal to 17.4 ± 18.3 %.

Discussion

Despite the traditional ideas about anatomical and functional isolation of motor systems from cognitive, modern researchers allow to assert that these systems are interconnected [6, 9, 10, 24, 28]. The base of movements formation is the coordinated activity of different brain systems of both those that directly control the realization of the motor act and those that are related with the processes of perceptions, attention and memory [17].

For the purpose to study the effect of the cognitive task on the spatio-temporal parameters of human walking, we used two tasks of different complexity: 1) sequentially pronounce aloud any known animals without repeating; 2) starting from a number 100, subtract 7 and pronounce the result aloud. The results of walking with additional cognitive tasks were compared with the results of normal walking at individually comfortable velocity.

It was revealed similar changes in the parameters of walking with an easier cognitive task (naming animals) in all groups. It should be noted that the spatial parameters had no significant changes. As opposed to the spatial parameters, most temporal ones in all groups were changed statistically, namely: there was an increase in the cycle time, swing time, the duration of the single and double support. Changing in these parameters logically led to a decrease in velocity and ambulation time. Therefore, equilibrium maintaining at walking with naming animals is realized with a longer overall support period in the step cycle of such walking, reducing the walking cadence and velocity and increasing the ambulation time.

The constant width of the support base and the angle of the feet turn in all groups may indicate that the magnitudes of the functional support base and angle of the feet turn at normal walking is sufficient to maintain posture and balance at walking with simultaneous performance of the cognitive task, as well as more rigid mechanisms of regulation of these two parameters [3, 4, 30].

At comparing the spatio-temporal parameters of walking with simultaneous cognitive task between groups of different age no statistically significant differences were found in male and female groups.

We did not find differences in cognitive performance between age groups.

At naming animals while walking, the cognitive component obviously appeared to be such a force of influence that it led to a change in not all walking parameters but only to a change in a number of temporal parameters. Thus, it can be reasonably assumed that temporal parameters at walking with an additional cognitive task begins to change already during the execution of the simplest cognitive tasks, and therefore are more labile than the spatial parameters that change as the complexity of the cognitive task increases.

Assessing changes in walking parameters under additional motor or cognitive tasks, it is important to consider that the spatial and temporal parameters of walking can indirectly evaluate the state of the CNS structures responsible for the walking parameters formation. Walking quality with the additional cognitive task tended to decrease in all investigated groups, as indicated by the results of comparing the FAP index at normal individually comfortable walking and walking with the additional cognitive task. Accordingly FAP went down for boys from 96.4 ± 4.0 % to 83.1 ± 3.9 %, for young men from 96.7 ± 4.9 % to 82.1 ± 2.2 %, for girls from 97.1 ± 3.9 % to

81.8±1.8 %, for young women from 96.7±3.9 % to 82.3±1.1 %, for middle-aged women from 96.8±5.3 % to 89.5±4.7 %. It is interesting that with age, especially among women, the percentage of FAP decreases: in girls by 15.3 %, in young women by 14.4 %, in middle-aged women by 7.4 %. Probably, such a decrease in FAP proves that performing a cognitive task while walking leads to a decrease of balance and body stability during the movement, and thus increases the risk of falls, so a significant decrease in FAP can be used as a diagnostic criterion in neurological practice.

More significant changes in walking were established during performing more complex (sequential subtraction 7 out of 100) cognitive task. Velocity decreased by 52.5 % in boys and 61.5 % in girls. The same effect of cognitive performance on walking velocity, but less power, has been observed in other studies [10]. At the same time, the cadence decreased by 44.1 % in boys and 52.6 % in girls, which is usual for slow walking [30].

It should be noted that there are conflicting results of studies of cognitive tasks effect on human walking parameters. There are reports of cognitive tasks no influence on walking of young healthy people as well as on healthy elderly people [18, 19, 21]. The authors used easy cognitive tasks as additional ones (verbal response to auditory stimulus, verbal response to visual stimulus, etc.) that required little cognitive effort, or perhaps gave priority exclusively to walking, which was studied less accurately, mostly using electronic footswitch systems. The direction of changes in the spatial-temporal parameters of walking with the simultaneous performance of the cognitive task in our study only in some cases coincided with those given in the literature. However, current research can reasonably argue that motor and cognitive systems are interconnected [9, 10]. The basis of motions formation is the coordinated activity of various brain systems, both those that directly control the implementation of the motor act and those related to the processes of perception, attention, and memory [17].

Thus, reducing walking speed while performing an additional task is likely to be a defensive reaction to maintain movement stability. On the other hand, there is evidence in the literature that slow walking speed, which is often accompanied by an increase in the variability of step cycle duration, contributes to gait instability [17]. Therefore, in our case, when arithmetic is concurrent with walking, a decrease in speed may indicate that such walking becomes unstable compared to ordinary walking. Instability may be associated with qualitative changes in walking control, which becomes less effective at decreased speed.

We have determined that both young men and young women have a decrease in walking speed with simultaneous counting due to an increase in all temporal parameters without exception and, first of all, due to the increase in stance time and swing time. The step cycle was restructured in the direction of reducing the parts of the swing time and single support time (by 3.9 % and 3.7

% for young men, young women by 7.6 % and 7.4 % respectively), and an increase in the parts of stance time and double support (2.7 % and 18.5 % for young men, 5.2 % and 34.7 % for young women respectively). Therefore, to maintain equilibrium at walking with the arithmetic task a longer overall support period in the step cycle of such walking helps. Moreover, the increased instability of walking with simultaneous calculation in comparison with ordinary walking is indicated by the increase of asymmetries of step time (from 0.010±0.001 s to 0.209±0.038 s), cycle time (from 0.010±0.001 s to 0.091±0.019 s), and young women also have an asymmetry in step length (from 1.620±0.120 cm to 2.602±0.201 cm).

FAP, while performing cognitive tasks, is critically reduced by 30.4 % in young men and 33.4 % in young women, indicating a significant reorganization of basic mechanisms for walking stability regulation with the participation of spinal and suprasegmental structures under the influence of powerful outputs from the highest cortical centers.

Invariability of support base width and feet rotation angles in both boys and girls may indicate that functional support base dimensions in normal walking is sufficient to maintain posture and balance even in walking with simultaneous performance of cognitive task, as well as on more rigid mechanisms of these two parameters regulation. The support base is the spatial parameter which stability is required to maintain medio-lateral and anterior-posterior walking stability. It is shown that the support base is the most stable parameter, which does not change with different walking paradigms. In our previous studies, it was found that support base did not change with many additional tasks [30].

We found a decrease in walking performance (as evidenced by a decrease in FAP) with additional tasks compared to ordinary walking performance in all examined groups. Several theories can be applied to explain the reason for the changes in the spatial-temporal organization of walking with cognitive task [26, 29]. According to the neuropsychological theory of "resource allocation", if both tasks performed simultaneously they require the use of resources that exceed the resource of central general ability, the performing a single task, or, even, both will worsen, regardless to the specific nature of the tasks. According to the modified version of the theory of "resource allocation", due to the ability of attention to be distributed, when it is dispersed to perform two tasks that need attention, it may deteriorate, even if the capacity of the resource is not exceeded [16].

Since naming animals requires coordination between the processes of articulation, phonation and respiration, this additional task can also be considered as a complex motor task. And according to the theory of "bottle neck", the performance of two similar by nature tasks reduces the quality of their performance [10]. But it is important that studies on the influence of cognitive tasks on the process of walking show that the cognitive tasks change walking even when they have no motor component [6]. Naming

animals while walking can be classified as a rhythmic activity. In the scientific literature there are some data that, while performing two rhythmic tasks of different frequencies, their powerful interference can occur [13]. Obviously, in our study, the rhythmic nature of naming animals could interfere with walking rhythm and thus provoke significant changes in walking.

We used one of the complex cognitive tasks, arithmetic, which requires maximum attention and memory. As a result, the quality of both walking and cognitive performance decreased, but the quality of counting (more than twice) declined more critically, in favor of moving forward and maintaining balance. Thus, the examined individuals subconsciously gave priority to walking. This is coordinated with the "first pose strategy" put forward by A. Shumway-Cook, according to which, in case of increasing threat of falling, the subject prefers late control or stability of walking over the performance of additional, secondary task in order to reduce risk of falling and injury [24].

Therefore, regulation of spatio-temporal parameters of walking depends on the work of all levels of nervous system. The basic spatio-temporal pattern is initiated by central generators of spinal cord rhythm, whose work is set up and modulated by supra-segmental structures, and layered commands from cerebral cortex can substantially change the basic pattern by creating an appropriate spatio-temporal model of walking.

Changes in spatio-temporal pattern of walking with simultaneous performance of certain tasks depend not only on task nature, but also increase in accordance with its difficulty. The greater impact of complex cognitive task on walking can be related to the mechanisms of information processing in CNS. Probably, in case of arithmetic counting, they were activated to a greater extent. In addition, counting is dependent on operative brain memory [2] and thus directly on executive function. Competition for executive function resource of two simultaneously performed tasks in walking conditions with additional cognitive task turned out to be quite intense. We have established a powerful influence of cognitive tasks on the spatial and temporal organization of walking, which showed itself in reduce of walking velocity, step length and increase of the contact duration of the lower extremities with the support surface (track) due to the increase in the duration of support and the duration of double support, and by reorganization of step cycle to increasing the part of contact with the track and reducing the duration swing phase.

Walking variability is a unique area that provides intellectual awareness of the risk of falls and future mobility decline. Dynamic higher-level walking control requires adaptability in the context of additional proposed tasks. Evaluation of walking data obtained is the key to a comprehensive assessment and study of dynamic gait control [7]. The data of our study argue for the possibility of using additional tasks as a tool of isolated influence on temporal (cognitive task similar to ours in type and complexity - animal naming) and spatial (motor task) gait parameters,

which allows to indirectly evaluate the functional state of different parts of the nervous system. Given the changes in quantitative and qualitative indicators of walking in different physiological paradigms, we can confidently state that walking is not an automatic process, but requires the use of various additional CNS resources, especially attention and cognitive resources.

The results obtained can be used to create more sophisticated physiological models of mechanisms for the formation of patterns of normal walking. Obtained indexes of spatial and temporal parameters of walking can be used as criteria for the assessment of normal walking, for the diagnosis and differential diagnosis in the neurology and traumatology and orthopedics, including early, subclinical and oligosymptomatic stages, to improve the effectiveness of treatment and at solving expert problems in the practice of rehabilitation treatment in order to expand the walking function and better performance of simultaneous tasks in sports medicine to evaluate the athlete's functionality in order to further involve sportsmen in a particular sport activity.

Further research is needed to understand the brain processes that underlie cognitive-motor interaction. Their understanding will improve procedures for both assessing human walking and developing new approaches to maintain functional independence in old people.

Conclusions

1. At a simpler cognitive task (animal naming) in all groups it was found that the spatial indices had no significant changes, most of the temporal parameters changed: there was an increase in the step cycle time, an increase in the swing time, the duration of the single and double support. Changing of these parameters resulted in a slower velocity and a longer ambulation time. Therefore, maintaining equilibrium at walking with animal naming aloud is due to a longer overall support period in the step cycle of such walking, reducing the cadence and velocity of walking and increasing the total ambulation time. Invariability of support base width and feet rotation angles in both boys and girls may indicate that functional support base dimensions in normal walking is sufficient to maintain posture and balance even in walking with simultaneous performance of cognitive task, as well as on more rigid mechanisms of these two parameters regulation.

2. At performing the second, more complex, cognitive task among all spatio-temporal parameters in young men and young women, only the support base, toe-in-out, step length difference was not significantly changed compared to ordinary walking. The other parameters have changed significantly. The integral indicator of walking quality (FAP) declined sharply by 30.4 % in young men and 33.4 % in young women, indicating a major reorganization of basic mechanisms for regulating of walking stability with the participation of spinal and supra-segmental structures under the influence of powerful outputs from the highest cortical centers.

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ВІКОВІ ОСОБЛИВОСТІ ХОДЬБИ ПРИ ОДНОЧАСНОМУ ВИКОНАННІ КОГНІТИВНИХ ЗАВДАНЬ

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Ходьба розглядається як комплексний когнітивний акт. Мета дослідження - аналіз вікових особливостей ходьби людини та її зміни при виконанні додаткових когнітивних завдань. За допомогою системи GAITRite® (CIR Systems Inc., Clifton, NJ) вивчали просторово-часові показники ходьби в 608 осіб обох статей віком 12-43 роки при звичайній ходьбі з довільною швидкістю та при виконанні додаткових когнітивних завдань: 1) послідовно без повторень називати відомі тварини; 2) починаючи з числа 100, послідовно віднімати 7 і називати отриманий результат. Статистичну обробку результатів проводили в ліцензійному пакеті "STATISTICA 5.5". При виконанні першого, простішого, завдання в усіх вікових групах просторові показники не мали достовірних змін. Більшість часових параметрів змінилися: збільшився загальний час крокового циклу, збільшилася тривалість переносу ніг, тривалість одиночної та подвійної опори. Отже, утримати рівновагу при ходьбі з одночасним називанням тварин допомагають триваліший загальний період опори, зниження темпу й швидкості ходьби. Незмінність ширини бази опори та кутів розвороту стоп свідчить про те, що величин функціональної бази опори та кутів розвороту стоп достатньо для збереження пози та рівноваги при ходьбі з одночасним виконанням когнітивного завдання, а також про більш жорсткі механізми регуляції цих двох параметрів. Часові показники ходьби є лабільнішими, ніж просторові параметри. З віком, особливо у представників жіночої статі, зменшується процент зниження інтегрального показника якості, "нормальності" ходьби (FAP): у дівчаток на 15,3 %, у дівчат на 14,4 %, у жінок середнього віку на 7,4 %. При виконанні другого, складнішого, арифметичного завдання у юнаків і дівчат тільки ширина бази опори, кути розвороту стоп, різниця між довжиною кроку правою й лівою ногою достовірно не змінилися. Середня швидкість, кількість кроків за хвилину, довжина звичайних і подвійних кроків, співвідношення довжини кроків до довжини відповідної ноги зменшилися. Кількість кроків, усі часові параметри, частка тривалості опори збільшилися. Показник FAP критично знижувався на 30,4 % у юнаків і на 33,4 % у дівчат, що свідчить про зниження рівня підтримки рівноваги та зниження стабільності тіла під час руху при виконанні когнітивного завдання під час ходьби та збільшення ризику падіння. Тому значне зниження FAP можна використовувати як діагностичний критерій в неврологічній практиці.

Ключові слова: просторові та часові параметри ходьби, різні вікові групи, ходьба з додатковим когнітивним завданням.

ВОЗРАСТНЫЕ ОСОБЕННОСТИ ХОДЬБЫ ПРИ ОДНОВРЕМЕННОМ ВЫПОЛНЕНИИ КОГНИТИВНЫХ ЗАДАНИЙ

Мороз В. М., Йолтуховский М. В., Власенко О. В., Московко Г. С., Богомаз О. В., Рокунец И. Л., Тищенко И. В., Костюк Л. В., Супрунов К. В.

Ходьба рассматривается как комплексный когнитивный акт. Цель исследования - анализ возрастных особенностей ходьбы человека и ее изменения при выполнении дополнительных когнитивных задач. С помощью системы GAITRite® (CIR Systems Inc., Clifton, NJ) изучали пространственно-временные показатели ходьбы у 608 добровольцев обоих полов в возрасте 12-43 года при обычной ходьбе с произвольной скоростью и при ходьбе с когнитивным заданием: 1) последовательно без повторений называть животных; 2) начиная с числа 100, последовательно отнимать 7 и называть полученный результат. Статистическую обработку результатов проводили в лицензионной программе "STATISTICA 5.5". При выполнении первого, более простого, задания во всех возрастных группах пространственные показатели не имели достоверных изменений. Большинство временных параметров изменились: увеличилось общее время шагового цикла, увеличилась продолжительность переноса ног, продолжительность одиной и двойной опоры. Таким образом, удержать равновесие при ходьбе с одновременным называнием животных помогают более длительный общий период опоры, снижение темпа и скорости ходьбы. Неизменность ширины базы опоры и углов разворота стоп свидетельствует о том, что величин функциональной базы опоры и углов разворота стоп достаточно для сохранения позы и равновесия при ходьбе с одновременным выполнением когнитивного задания, а также о более жестких механизмах регуляции этих двух параметров. Временные показатели ходьбы более лабильны, чем пространственные показатели. С возрастом, особенно у представителей женского пола, уменьшается процент показателя "нормальности" ходьбы (FAP): у девочек на 15,3 %, у девушек на 14,4 %, у женщин среднего возраста на 7,4 %. При выполнении второго, более сложного, арифметического задания у юношей и девушек только ширина базы опоры, углы разворота стоп, разница между длиной шага правой и левой ногой достоверно не изменились. Средняя скорость, количество шагов в минуту, длина обычных и двойных шагов, соотношение длины шагов к длине соответствующей ноги уменьшились. Количество шагов, все временные параметры, процентная доля продолжительности опоры увеличились. Показатель FAP критически снижался на 30,4 % у юношей и на 33,4 % у девушек, что свидетельствует о снижении уровня поддержания равновесия и снижении стабильности тела во время ходьбы с одновременным выполнением когнитивного задания и увеличение риска падения. Поэтому значительное снижение FAP можно использовать как диагностический критерий в неврологической практике.

Ключевые слова: пространственные и временные параметры ходьбы, разные возрастные группы, ходьба с дополнительным когнитивным заданием.