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Original Article

Influence of treadmill speed selection on gait parameters compared to overground walking in subacute rehabilitation patients

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Abstract. [Purpose] Treadmill-based interventions are widely utilized in rehabilitation due to their advantages of providing controlled environments and enabling individualized training. However, the differences between overground and treadmill walking during the subacute rehabilitation phase remain incompletely understood. This study aimed to compare gait parameters between treadmill walking at varying speeds and overground walking in a subacute rehabilitation setting. [Participants and Methods] A total of 42 inpatients with cerebrovascular and orthopedic conditions were recruited from a convalescent rehabilitation ward. Gait parameters were measured using the Gait Real-time Analysis Interactive Lab (GRAIL) system during comfortable overground walking and treadmill walking at various speeds, including self-selected comfortable speeds and speeds matched to overground walking. Walking speed, stride length, cadence, and step width were calculated without markers and compared across conditions. [Results] The comfortable treadmill walking speed was significantly lower than the overground walking speed (mean [standard deviation]: 0.85 [0.23] m/s vs. 1.20 [0.20] m/s). Stride length was significantly shorter during treadmill walking at comfortable speeds compared to overground walking (0.86 [0.22] m vs. 1.21 [0.18] m), whereas step width was significantly wider (0.17 [0.04] m vs. 0.13 [0.03] m). [Conclusion] Maintaining cadence at reduced treadmill speeds promotes comfortable endurance training in subacute rehabilitation patients.
Key words: Treadmill walking, Overground walking, Gait parameters

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INTRODUCTION

Gait impairment, a common sequela of neurological disorders such as stroke and musculoskeletal conditions, like osteoarthritis, significantly affect patient populations globally[1, 2]. Restoring functional ambulation is a key goal in rehabilitation as it is essential for promoting independence and social participation[3]. To address these challenges, various gait training modalities have been developed, with treadmill-based interventions gaining recognition for their effectiveness in promoting motor recovery and improving gait function[4–6].

Treadmill training aligns well with contemporary rehabilitation principles, particularly those emphasizing task-specific repetitive practices to drive motor recovery and enhanced function[7, 8]. This approach offers several advantages. First, it facilitates continuous practice within a limited space, potentially increasing gait training frequency[9]. Second, the integration

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of body weight support systems allows for the earlier initiation of gait training in patients with limited weight-bearing capacity[10]. Third, robot-assistive technologies can guide joint movements and improve the precision of gait patterns[11]. These features, along with the ability to precisely control walking speed and duration, support the development of individualized and progressive rehabilitation protocols.

These characteristics make treadmill training particularly beneficial for enhancing neuroplasticity and improving functional outcomes[12]. Specifically, treadmill training can affect two major aspects of walking ability: walking speed and walking endurance, both of which are essential for patients' functional independence. High-speed treadmill training has been shown to effectively improve walking speed[13], and high-dose training at appropriate speeds has been proved to enhance walking endurance[14]. The efficacy of these training methods has been demonstrated in diverse patient populations. For example, studies have shown improvements in walking speed and distance in patients with stroke[14, 15], enhanced step length and balance ability in patients with Parkinson's disease[16, 17], and significant gains in gait speed and step length in patients with knee osteoarthritis using body-weight-supported treadmill training[18]. These findings align with the current stroke rehabilitation guidelines, which recommend high-intensity, task-specific practice to improve walking ability in various conditions[19]. Thus, treadmill-based interventions represent a significant advancement toward more adaptable and comprehensive rehabilitation strategies. However, to optimize these interventions, it is crucial to determine the treadmill settings that best replicate the overground walking patterns of different patient populations.

Notably, gait patterns differed between overground and treadmill walking. The inherent instability of treadmill walking necessitates adaptations in gait patterns not typically observed during overground walking[20]. Although there are many similarities, the possibility of differences based on individual characteristics should not be overlooked. For instance, a systematic review by Semaan et al. found that spatiotemporal parameters such as walking speed, step length, and cadence were generally similar between treadmill and overground walking in healthy young adults[21]. In contrast, Watt et al. observed increased cadence and decreased stride length during treadmill walking in healthy older adults[22], suggesting that gait differences may vary depending on the population.

In the patient populations, these differences were even more pronounced. Puh and Baer reported both positive (improved symmetry) and negative (decreased cadence and increased double support time) changes in the gait patterns of chronic stroke patients during treadmill walking at matched speeds[23]. More recently, Van Bladel et al. found significantly lower self-selected walking velocities on self-paced treadmills compared to overground walking in stroke patients, affecting other spatiotemporal parameters. Interestingly, gait variability and symmetry measures remained similar between conditions[24].

Although previous research has demonstrated the benefits of treadmill-based interventions in patients in the subacute phase, there is still a need for a more precise understanding of how to optimize treadmill walking speed for effective training. For improving walking endurance, the optimal treadmill walking speed should be set at which patients can walk comfortably, as this enables them to practice walking for longer distance. To optimize such treadmill-based endurance training for patients in the subacute phase, it would be beneficial if we could estimate appropriate treadmill speeds based on patients' comfortable overground walking speeds. While this relationship between overground and treadmill walking speeds is essential for tailoring treadmill-based rehabilitation to the unique characteristics of subacute patients, such research has not yet been conducted. Therefore, this study aimed to compare gait parameters between treadmill and overground walking in inpatients during subacute rehabilitation, with a specific focus on identifying the relationship between comfortable walking speeds in both conditions. Clarification of this relationship will provide practical guidance for determining appropriate treadmill speeds that enable sustained walking practice in this population.

PARTICIPANTS AND METHODS

The patients were recruited from a convalescent rehabilitation ward. The inclusion criteria were as follows: (1) the ability to walk independently within the ward; (2) the ability to walk on a treadmill without assistive devices under the supervision of a physical therapist; and (3) provision of informed consent. The exclusion criteria were: (1) uncontrolled hypertension (systolic blood pressure ≥180 mm Hg or diastolic blood pressure ≥120 mm Hg), (2) resting heart rate ≥120 bpm, (3) exercise limitations due to cardiac or respiratory disorders, and (4) cognitive impairments such as higher brain dysfunction or dementia that would interfere with understanding the study procedures. The participants were classified into two groups based on their primary diagnoses: cerebrovascular and orthopedic diseases. Written informed consent was obtained from all participants. This study was approved by the Ethics and Conflict of Interest Committee of the National Center for Geriatrics and Gerontology (Approval No. 1438).

The participants walked along a 9-meter walkway at a self-selected comfortable speed. Gait kinematics were captured using a system of nine synchronized cameras (DSC-RX0M2; Sony Corp., Tokyo, Japan) positioned around the walkway, with video data sampled at 60 Hz. Cameras were arranged to ensure full-body capture throughout the central portion of the walkway, while allowing for acceleration and deceleration zones at the beginning and end of the walkway.

Treadmill trials were conducted using the Gait Real-time Analysis Interactive Lab (GRAIL) system. Gait kinematics were recorded using seven synchronized cameras (DSC-RX0M2; Sony Corp., Tokyo, Japan) arranged around a treadmill. Before the treadmill trials, each participant's self-selected walking speed was determined via a 10-meter walk test. Subsequently, treadmill velocities were incrementally adjusted to 50, %, 70, 80, 90, and 100% of the participants' self-selected overground walking speeds. To mitigate the two potential issues associated with treadmill walking, we implemented the following strategies: First, to compensate for the lack of forward optical flow, which is a common limitation of treadmill walking[25], a large screen in front of the treadmill displayed a dynamic visual scene synchronized with the participant's walking speed. Second, to reduce any unfamiliarity with treadmill use, all participants completed a familiarization session of at least 10 min of treadmill walking on the day prior to data collection[26]. The participants walked for 30 s at each speed, with data recording was initiated once the treadmill reached the target speed and the gait pattern stabilized.

Joint center points were calculated from the recorded videos using Theia3D (Theia Markerless Inc., Kingston, ON, Canada). Using the estimated joint center points, gait cycle events, walking speed, stride length, cadence, and step width were calculated using Visual3D (Has-Motion Inc., Kingston, ON, Canada). The foot strikes and toe-off events were determined based on the method reported by Zeni et al[27]. The analysis excluded approximately two gait cycles at the beginning and end of each walking trial.

For the parameters of walking speed, stride length, cadence, and step width, a two-factor mixed-design analysis of variance (ANOVA) was performed with the between-participants factor being "Group" (cerebrovascular diseases and orthopedic diseases group) and the within-participants factor being "Condition" (three walking conditions). For the repeated measures factor "Condition", Mauchly's test of sphericity was conducted; if the assumption of sphericity was violated, the Greenhouse–Geisser correction was applied to adjust the degrees of freedom. When significant main effects or interaction effects were observed, post hoc pairwise comparisons between conditions were conducted using the Bonferroni correction. The level of statistical significance was set at $p<0.05$, and the results are reported as mean ± standard deviation (SD). Statistical analyses were performed using R version 4.4.1[28].

RESULTS

Forty-two patients admitted to the convalescent rehabilitation ward of the National Center for Geriatrics and Gerontology participated in this study. The mean age of participants was 71.8 ± 10.6 years, height was 1.56 ± 0.10 m, and weight was 57.1 ± 12.5 kg, with 20 males. The breakdown of conditions included 20 patients with cerebrovascular diseases (70.6 ± 11.4 years, 1.61 ± 0.08 m, 60.5 ± 12.9 kg, 14 males) and 22 patients with orthopedic diseases (72.8 ± 10.0 years, 1.52 ± 0.11 m, 54.0 ± 11.5 kg, 6 males) (Table 1). The mean time from onset to measurement for patients with cerebrovascular diseases was 62.5 ± 30.1 days, while the mean time from surgery to measurement for patients with orthopedic diseases was 51.5 ± 24.2 days.

For treadmill walking, the perceived comfortable speed varied among participants as a percentage of their comfortable overground walking speed: 100% (one participant), 90% (four participants), 80% (twelve participants), 70% (thirteen participants), 60% (eight participants), and 50% (four participants). Most participants found 70% (thirteen participants) or 80% (twelve participants) of their overground speed to be the most comfortable on the treadmill. Walking speed was a significant main effect between conditions ($F(2, 80)=195.10$, $p<0.001$), with comfortable treadmill walking being significantly slower than both overground walking and treadmill walking at matched speeds (Table 2).

Stride length was also a significant main effect between conditions ($F(2, 80)=178.22$, $p<0.001$), with significant differences between all conditions (all $p<0.001$). The stride length was the longest during overground walking and the shortest during comfortable treadmill walking (Table 2).

Cadence was a significant main effect between conditions ($F(2, 80)=42.13$, $p<0.001$). Treadmill walking at matched speed showed significantly higher cadence than both comfortable overground walking and comfortable treadmill walking, while no difference was found between the two comfortable walking conditions (Table 2).

Table 1. Details of patients' disease classifications

Participants (n=42)	
Age (years)	71.8 ± 10.6
Gender (male/female)	20/22
Height (m)	1.56 ± 0.10
Weight (kg)	57.1 ± 12.5
Orthopedic diseases	
Spinal disease	15
Hip joint disease	3
Knee joint disease	3
Others (pubic bone fracture)	1
Cerebrovascular disease	
Cerebral hemorrhage	8
Cerebral infarction	9
Others (chronic subdural hematoma,subarachnoid hemorrhage)	3

Table 2. Comparison of gait parameters between overground and treadmill walking conditions

	Mean (SD)			Post-hoc tests		
	Overground walking	Treadmill walking (comfortable)	Treadmill walking (matched)	Overground vs. Treadmill (comfortable)	Overground vs. Treadmill (matched)	Treadmill (comfortable) vs. Treadmill (matched)
Walking speed (m/s)	1.20 (0.20)	0.85 (0.23)	1.18 (0.19)	***	*	***
Stride length (m)	1.21 (0.18)	0.86 (0.22)	1.10 (0.19)	***	***	***
Cadence (steps/min)	119 (7.07)	118 (9.37)	129 (9.24)	-	***	***
Step width (m)	0.13 (0.03)	0.17 (0.04)	0.17 (0.04)	***	***	-

Asterisks indicate significant differences (*p<0.05, **p<0.01, ***p<0.001).

Finally, step width demonstrated significant main effects for condition ($F(2, 80)=47.45$, $p<0.001$) and group ($F(1, 40)=5.17$, $p=0.028$), with no significant interaction between group and condition ($F(2, 80)=0.00$, $p=0.996$). The step width was significantly wider during both treadmill conditions compared to overground walking, with no difference between the two treadmill conditions (Table 2). Specifically, in the musculoskeletal group, the step width was 0.12 ± 0.02 m during comfortable overground walking, increasing to 0.16 ± 0.03 m during both treadmill conditions. In the neurological group, the step width was 0.14 ± 0.04 m during comfortable overground walking, increasing to 0.18 ± 0.04 m during both treadmill conditions.

DISCUSSION

This study compared gait parameters between treadmill and overground walking in patients in a convalescent rehabilitation ward. The primary findings indicated that the subjectively comfortable treadmill walking speed for convalescent patients was approximately 70–80% of their overground walking speed. During treadmill walking, there was a significant decrease in both walking speed and stride length compared with overground walking. Conversely, cadence was maintained, and step width significantly increased. The maintenance of cadence is considered a key factor in determining comfortable walking speed. These observations suggest that these subacute patients adopt a different gait pattern on the treadmill, reducing their speed to maintain walking stability. Furthermore, when the patients maintained a speed equivalent to their overground walking pace on a treadmill, they shifted to a gait pattern that enhanced their walking stability.

Our results demonstrated a more pronounced difference in comfortable walking speed on the treadmill compared with previous studies. Although a reduction in speed (0.15 m/s) and stride length (0.16 m) during treadmill walking at a comfortable speed has been previously reported[29)], the changes observed in our study with convalescent patients were more substantial, with speed reduction reaching 0.35 m/s and stride length shortening by 0.35 m. Yang and King noted a tendency to adopt a more cautious gait on the treadmill[30)], and thus the observed decrease in walking speed and shortened stride length can be interpreted as a reasonable strategy to maintain gait stability.

Similarly, the maintenance of cadence during treadmill walking comparable to overground walking, and the significant increase in cadence during treadmill walking at speeds equivalent to overground walking can be interpreted as a strategy to maintain stability. Hak et al. reported that an increased cadence contributes to balance maintenance during walking[31)]. It is plausible that the subacute patients maintain lateral stability on inherently unstable treadmill surfaces by shortening their step lengths and increasing their walking rhythm. Furthermore, the consistent maintenance of cadence during treadmill walking suggests that the regularity of the gait rhythm likely contributes to the stabilization of motor control. Hollman et al. also noted that maintaining a consistent rhythm preserves movement smoothness, thereby enhancing gait stability[32)]. It can be inferred that these patients efficiently control their movements on the treadmill by maintaining a constant rhythm.

Regarding step width, our study observed differences compared with previous studies. Yang and King, in their study on healthy young adults, found no significant difference in step width between overground and treadmill walking[30)]. However, our study on the subacute patients revealed an increase of 0.04 m in step width during treadmill walking. Widening step width is a strategy used to expand the base of support and enhance lateral stability during gait[33–35)]. Thus, the patients may have adopted this strategy to maintain gait stability under the moving surface conditions of treadmill walking. Furthermore, our study observed significant differences in step width increase among the disease groups. Notably, the neurological disease group exhibited more pronounced increases in step width. Considering that neurological diseases impair the neural networks governing balance control[36, 37)], this result may indicate that patients with neurological diseases require more active strategies to stabilize their gait than those with musculoskeletal diseases, possibly to compensate for their reduced balance capabilities.

Conversely, as Dingwell et al. noted, treadmills often provide a narrower walking path compared to overground surfaces[38)]. However, the treadmill used in our study offered sufficient width to allow lateral movement during walking, enabling participants to widen their step width to maintain stability. This design feature may have enabled the convalescent patients to adopt a strategy of increasing step width for lateral stability. Furthermore, as Bayat et al. pointed out, the proprioceptive input on a treadmill differs from that experienced during overground walking[39]. This difference in sensory feedback may have contributed to the adoption of more conservative gait patterns. The altered proprioceptive input combined with the moving surface of the treadmill likely influenced the patients' gait strategies, prompting them to prioritize stability through increased step width and other adaptive mechanisms.

The findings of this study have significant implications for the design of rehabilitation programs utilizing treadmills. Specifically, treadmill walking poses a slightly higher level of difficulty than overground walking at the same speed for convalescent patients who have recently regained the ability to walk. It is advisable to develop a graduated protocol that ensures patient safety and stability while progressively increasing walking speed. An approach that initiates training at 70–80% of overground walking speed and gradually increases based on patient adaptation might be recommended. Since patients naturally maintain their preferred cadence even at reduced speeds, this approach allows them to practice walking more comfortably and safely. Furthermore, effective improvements in walking ability may be achieved by appropriately combining treadmill walking training with overground walking. Incorporating interventions aimed at improving step width and stride length using visual feedback and rhythmic stimulation could also be beneficial[40]. This comprehensive approach addresses specific gait adaptations observed during treadmill walking while facilitating the transfer of skills to overground walking.

This study had several limitations. First, due to the relatively small sample size and heterogeneous patient population with varying disease characteristics, caution should be exercised when generalizing the results. Additionally, since we focused on individuals capable of independent walking, further investigations are necessary for populations requiring walking aids or assistance. Moreover, the cross-sectional design of this study precluded evaluation of long-term adaptation or training effects. Third, a significant difference was observed between comfortable overground and treadmill walking speed, even when the treadmill speed was set to match the participant's comfortable overground walking speed. This discrepancy may be partly attributed to our method of determining treadmill speeds, which involved using a 10-meter walk test prior to the treadmill trials to establish each participant's self-selected walking speed. However, the actual difference in speed was only 0.02 m/s, which is likely of minimal clinical significance. Lastly, future research should prioritize larger-scale studies with more homogeneous populations and employ longitudinal designs to assess the long-term effects of treadmill training.

It is crucial to conduct further investigations that address these limitations to enhance understanding of treadmill walking in rehabilitation settings and develop more effective evidence-based training protocols for subacute patients.

In conclusion, this study examined the differences in gait parameters between treadmill walking and overground walking in convalescent rehabilitation patients. The results confirmed that during treadmill walking, compared to overground walking, there was a decrease in walking speed and stride length, along with an increase in step width, while cadence was maintained. The preservation of cadence despite other gait parameter changes suggests that patients adopt specific gait strategies to maintain both stability and walking comfort during treadmill walking. These insights underscore the importance of adjusting treadmill speed according to individual patient needs in rehabilitation settings utilizing treadmills. Future research should focus on elucidating optimal training protocols from a larger-scale and long-term perspective.

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Conflicts of interest

The authors declare no conflicts of interest.

REFERENCES

1) Brandes M, Schomaker R, Möllenhoff G, et al.: Quantity versus quality of gait and quality of life in patients with osteoarthritis. Gait Posture, 2008, 28: 74–79. [Medline] [CrossRef]
2) Benjamin EJ, Blaha MJ, Chiuve SE, et al. American Heart Association Statistics Committee and Stroke Statistics Subcommittee: Heart Disease and Stroke Statistics-2017 update: a report from the American Heart Association. Circulation, 2017, 135: e146–e603. [Medline] [CrossRef]
3) Mehrholz J, Thomas S, Kugler J, et al.: Electromechanical-assisted training for walking after stroke. Cochrane Database Syst Rev, 2020, 10: CD006185. [Medline]
4) Baker PA, Evans OM, Lee C: Treadmill gait retraining following fractured neck-of-femur. Arch Phys Med Rehabil, 1991, 72: 649–652. [Medline]
5) Hesse S, Bertelt C, Jahnke MT, et al.: Treadmill training with partial body weight support compared with physiotherapy in nonambulatory hemiparetic patients. Stroke, 1995, 26: 976–981. [Medline] [CrossRef]
6) Visintin M, Barbeau H, Korner-Bitensky N, et al.: A new approach to retrain gait in stroke patients through body weight support and treadmill stimulation. Stroke, 1998, 29: 1122–1128. [Medline] [CrossRef]
7) Hornby TG, Reisman DS, Ward IG, et al. and the Locomotor CPG Appraisal Team: Clinical practice guideline to improve locomotor function following chronic stroke, incomplete spinal cord injury, and brain Injury. J Neurol Phys Ther, 2020, 44: 49–100. [Medline] [CrossRef]
8) Kleim JA, Jones TA: Principles of experience-dependent neural plasticity: implications for rehabilitation after brain damage. J Speech Lang Hear Res, 2008, 51: S225–S239. [Medline] [CrossRef]

9) Hollman JH, Watkins MK, Imhoff AC, et al.: A comparison of variability in spatiotemporal gait parameters between treadmill and overground walking conditions. Gait Posture, 2016, 43: 204–209. [Medline] [CrossRef]
10) Hesse S, Sawaki L: Treadmill training with partial body weight support after stroke: a review. NeuroRehabilitation, 2008, 23: 55–65. [Medline]
11) Aimoto K, Matsui T, Asai Y, et al.: Gait improvement in stroke patients by Gait Exercise Assist Robot training is related to trunk verticality. J Phys Ther Sci, 2022, 34: 715–719. [Medline] [CrossRef]
12) Belda-Lois JM, Mena-del Horno S, Bermejo-Bosch I, et al.: Rehabilitation of gait after stroke: a review towards a top-down approach. J Neuroeng Rehabil, 2011, 8: 66. [Medline] [CrossRef]
13) Wada Y, Kondo I, Sonoda S, et al.: Preliminary trial to increase gait velocity with high speed treadmill training for patients with hemiplegia. Am J Phys Med Rehabil, 2010, 89: 683–687. [Medline] [CrossRef]
14) Mehrholz J, Thomas S, Elsner B: Treadmill training and body weight support for walking after stroke. Cochrane Database Syst Rev, 2017, 8: CD002840. [Medline]
15) Mackay-Lyons M, McDonald A, Matheson J, et al.: Dual effects of body-weight supported treadmill training on cardiovascular fitness and walking ability early after stroke: a randomized controlled trial. Neurorehabil Neural Repair, 2013, 27: 644–653. [Medline] [CrossRef]
16) Bello O, Sanchez JA, Lopez-Alonso V, et al.: The effects of treadmill or overground walking training program on gait in Parkinson's disease. Gait Posture, 2013, 38: 590–595. [Medline] [CrossRef]
17) Frenkel-Toledo S, Giladi N, Peretz C, et al.: Treadmill walking as an external pacemaker to improve gait rhythm and stability in Parkinson's disease. Mov Disord, 2005, 20: 1109–1114. [Medline] [CrossRef]
18) Chen HX, Zhan YX, Ou HN, et al.: Effects of lower body positive pressure treadmill on functional improvement in knee osteoarthritis: a randomized clinical trial study. World J Clin Cases, 2021, 9: 10604–10615. [Medline] [CrossRef]
19) Winstein CJ, Stein J, Arena R, et al. American Heart Association Stroke Council, Council on Cardiovascular and Stroke Nursing, Council on Clinical Cardiology, and Council on Quality of Care and Outcomes Research: Guidelines for adult stroke rehabilitation and recovery: a guideline for healthcare professionals from the American Heart Association/American Stroke Association. Stroke, 2016, 47: e98–e169. [Medline] [CrossRef]
20) Vickery-Howe DM, Bonanno DR, Dascombe BJ, et al.: Physiological, perceptual, and biomechanical differences between treadmill and overground walking in healthy adults: a systematic review and meta-analysis. J Sports Sci, 2023, 41: 2088–2120. [Medline] [CrossRef]
21) Semaan MB, Wallard L, Ruiz V, et al.: Is treadmill walking biomechanically comparable to overground walking? A systematic review. Gait Posture, 2022, 92: 249–257. [Medline] [CrossRef]
22) Watt JR, Franz JR, Jackson K, et al.: A three-dimensional kinematic and kinetic comparison of overground and treadmill walking in healthy elderly subjects. Clin Biomech Bristol, 2010, 25: 444–449. [Medline] [CrossRef]
23) Puh U, Baer GD: A comparison of treadmill walking and overground walking in independently ambulant stroke patients: a pilot study. Disabil Rehabil, 2009, 31: 202–210. [Medline] [CrossRef]
24) Van Bladel A, De Ridder R, Palmans T, et al.: Comparing spatiotemporal gait parameters between overground walking and self-paced treadmill walking in persons after stroke. Disabil Rehabil, 2023, 45: 1016–1021. [Medline] [CrossRef]
25) Warren WH Jr, Kay BA, Zosh WD, et al.: Optic flow is used to control human walking. Nat Neurosci, 2001, 4: 213–216. [Medline] [CrossRef]
26) Meyer C, Killeen T, Easthope CS, et al.: Familiarization with treadmill walking: how much is enough? Sci Rep, 2019, 9: 5232. [Medline] [CrossRef]
27) Zeni JA Jr, Richards JG, Higginson JS: Two simple methods for determining gait events during treadmill and overground walking using kinematic data. Gait Posture, 2008, 27: 710–714. [Medline] [CrossRef]
28) Team RC: A language and environment for statistical computing Vienna, Austria: R foundation for statistical computing; 2024, https://www.R-project.org/
29) Dal U, Erdogan T, Resitoglu B, et al.: Determination of preferred walking speed on treadmill may lead to high oxygen cost on treadmill walking. Gait Posture, 2010, 31: 366–369. [Medline] [CrossRef]
30) Yang F, King GA: Dynamic gait stability of treadmill versus overground walking in young adults. J Electromyogr Kinesiol, 2016, 31: 81–87. [Medline] [CrossRef]
31) Hak L, Houdijk H, Beek PJ, et al.: Steps to take to enhance gait stability: the effect of stride frequency, stride length, and walking speed on local dynamic stability and margins of stability. PLoS One, 2013, 8: e82842. [Medline] [CrossRef]
32) Hollman JH, McDade EM, Petersen RC: Normative spatiotemporal gait parameters in older adults. Gait Posture, 2011, 34: 111–118. [Medline] [CrossRef]
33) McAndrew Young PM, Dingwell JB: Voluntary changes in step width and step length during human walking affect dynamic margins of stability. Gait Posture, 2012, 36: 219–224. [Medline] [CrossRef]
34) Wu M, Matsubara JH, Gordon KE: General and specific strategies used to facilitate locomotor maneuvers. PLoS One, 2015, 10: e0132707. [Medline] [CrossRef]
35) Reimann H, Fettrow T, Jeka JJ: Strategies for the control of balance during locomotion. Kinesiol Rev, 2018, 7: 18–25. [CrossRef]
36) Pollock C, Eng J, Garland S: Clinical measurement of walking balance in people post stroke: a systematic review. Clin Rehabil, 2011, 25: 693–708. [Medline] [CrossRef]
37) Shumway-Cook A, Woollacott MH, Rachwani J, et al.: Motor control: translating research into clinical practice, 6th ed. Philadelphia: Lippincott Williams & Wilkins, 2023.
38) Dingwell JB, Cusumano JP, Cavanagh PR, et al.: Local dynamic stability versus kinematic variability of continuous overground and treadmill walking. J Biomech Eng, 2001, 123: 27–32. [Medline] [CrossRef]
39) Bayat R, Barbeau H, Lamontagne A: Speed and temporal-distance adaptations during treadmill and overground walking following stroke. Neurorehabil Neural Repair, 2005, 19: 115–124. [Medline] [CrossRef]
40) Chamorro-Moriana G, Moreno AJ, Sevillano JL: Technology-based feedback and its efficacy in improving gait parameters in patients with abnormal gait: a systematic review. Sensors (Basel), 2018, 18: 142. [Medline] [CrossRef]