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Dynamic Stability Analysis of Random Multi-Obstacle Crossing in Elderly

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Abstract. To improve the accuracy of dynamic stability analysis of gait across obstacles. The conventional kinematics parameters and temporal dynamic parameters were calculated and compared. The dynamic stability control ability of the young group, the old group, and the fall group was analyzed when crossing obstacles of random height. The kinematic parameters can express the difference in dynamic stability caused by aging, and the temporal dynamic stability parameters can express the subtle differences between the fall group and the elderly group, and the two-dimensional ROSa Shannon entropy is more sensitive. This paper analyzes the performance of different parameters in analyzing the difference in dynamic stability when crossing obstacles of random height, which improves the accuracy of the dynamic stability analysis method for crossing obstacles.

Keywords: Stumble; Elderly; Temporal dynamic stability parameters; Random multi-obstacle.

1. Introduction

In non-disabled older adults, tripping disorders have been recognized as a leading cause of falls, accounting for 33% to 53% of all falls [1, 2], and as a leading cause of fractures in older people. The literature shows that most trips occur when crossing obstacles [3]. Compared with normal flat walking, people tend to adopt different walking patterns when crossing obstacles, which may increase the possibility of subsequent falls in contact with obstacles [4].

To reduce the risk of stumbling during walking in the elderly, it is particularly important to study the walking instability of the elderly in different obstacle gait environments using methods of motion biomechanics based on sociological and epidemiological studies. Only by clarifying the intrinsic mechanism and individual differences of walking instability in the elderly can targeted fall prevention strategies be developed to minimize the risk of tripping in the elderly.

In the existing biomechanical research of motion, in terms of obstacle setting. The analysis of tripping causes is carried out by using biomechanical experimental methods, which mainly include three basic methods: manually or automatically starting obstacles to prevent the swing leg from developing to the middle and late stage of swing [5]; Tethering based perturbation, consisting of a tether or rope attached to the subject's ankle (left, right, or both sides), abruptly tightened during swing to act as a tripping obstacle [6]; Sudden acceleration or deceleration of the treadmill to change the exercise environment of the subject [7]. It has been verified by experiments that the manual or automatic obstacle-starting method is more reasonable. Operational problems in tethering-based methods have rarely been reported, and because tethering tenses the foot, the extent of interference with tripping remains unclear [8]. In contrast, treadmill-induced tripping does not correspond to real-life tripping, since the treadmill interferes with the support leg, whereas real-life tripping interferes with the swing leg. The sudden acceleration or deceleration of the treadmill is quite different from the real tripping event [9]. Moreover, most of the above studies focused on single obstacles, or gait across obstacles with regular obstacles, which is not enough to simulate perturbations in the real world.

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In summary, this paper will calculate the traditional kinematics parameters, temporal dynamic stability parameters, and other parameters to analyze the performance of different people when they continuously cross obstacles of random height, to express the differences in people's dynamic stability control ability.

2. Experiment

2.1 Participants

Thirty people participated in the study, involving ten healthy young (Young: 22-29 years old), ten healthy elderly (Elderly: 63-79 years old), and ten elderly with a history of stumbles (Faller: 61-79 years old). The criterion for inclusion in the Faller category was a self-report of tripping once or more within the past three months [10]. The participants reported no history of neurological pathology, head trauma, vestibular dysfunction, or any disease that may be dangerous during the experiment. Written informed consent was collected before testing. The experimental protocol was approved by the Office of Research Ethics.

2.2 Test Configurations

Experimental measurements were composed of (1) motion analysis system with 15 cameras (Motion Analysis Corp., Santa Rosa, CA, USA, displacement error ≤ 0.1mm) to capture three-dimensional kinematic gait information; (2) plantar pressure acquisition (Tekscan Matscan, Tekscan Inc., South Boston, USA) to collect pressure distributions underneath foot, with sensor spatial resolution of 4 sensels/cm^2; (3) Four obstacles for obstacle crossing testing, included 10cm, 15cm, 20cm and 25cm.

2.3 Protocol

The participants were dressed in experimental tights and antiskid socks, with a total of 26 reflective markers defining a 15-segment model, in addition, markers were also set on both ends of each obstacle to calculate the relevant kinematics parameters. Each participant was collected three times, and the movement data acquisition frequency was 60Hz. If the obstacle was touched off, the data acquisition was restarted. All data were smoothed using a fourth-order Butterworth low-pass filter with a cut-off frequency of 6 Hz.

3. Methods

In this article, toe-obstacle distance (TOD), heel-obstacle distance (HOD), toe-obstacle clearance (TOC), Fréchet Distance of Region of Velocity Stability in 2-D (ROSvFD2-D), Probability of Instability of ROSv (ROSvIP2-D) and Shannon Entropy of ROSv in 2-D (ROSaSE2-D) were involved. All the calculated results were analyzed by one-way ANOVA or Kruskal-Wallis/Wilcoxon non-parametric test (SPSS ver 20). The significance level was $\alpha = 0.05$.

The randomized design in the continuous obstacle-crossing experiment was generated using the random. shuffle() method of Python software.

Markers on participants and obstacles were used to calculate toe-obstacle distance (TOD), heel-obstacle distance (HOD), and toe-obstacle clearance, respectively (TOC) [11]. Since the obstacles are placed randomly, it is of no practical physical significance to compare the kinematic parameters of each stride action in step order one by one. Therefore, in this paper, the sum of the TOD values of the four obstacle-crossing actions was defined as the TOD of the subject continuously crossing the random obstacle, and the HOD and TOC were the same as above.

The whole-body COM was calculated as the weighted sum of 15 body segments [12]. The calculation methods of ROSv2-D were referred to in the previous research [13, 14].]. $\widetilde{X\dot{Y}}_{TO}=1-\widetilde{XY}_{TO}$ were used as the standard curve, and the Fréchet distance between the participant's sample curve

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and the standard curve in 2-D was calculated as ROSvFD2-D. The ROSv curves beyond the stability boundary were locally integrated, and the ratio of the local integral to the total area was defined as ROSvIP2-D. The ROSa curve was obtained by differentiating the ROSv curve, and the ROSa Shannon entropy was obtained by Multifractal Analysis. Assuming that the ROSa curve of the participant was a continuous random variable, its instability can be expressed by Shannon entropy.

4. Results

The results of kinematic parameters across four consecutive obstacles of random height showed that TOD and HOD increased significantly with age (Fig. 1). The TOD of the young group (22.19±4.68 cm) was significantly lower than that of the elderly group (42.53±16.01 cm, *p*<0.05) and the fall group (37.60±16.69 cm, *p*<0.05). The HOD of the young group (18.58±6.83 cm) was significantly lower than that of the elderly group (33.62±14.64 cm, *p*<0.05). TOC did not show a significant trend of change with age. In addition, no significant differences were found in the kinematic parameters between the elderly group and the fall group, regardless of TOD, HOD, or TOC.

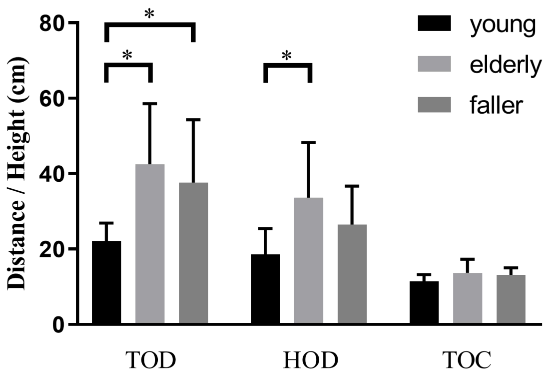

Fig. 1 TOD, HOD, and TOC in each group with the increase of obstacle height. (*p< 0.05).

As shown in Figure 2, with the increase of age and the occurrence of stumble history, ROSvFD2-D gradually increased, and the differences between the fall group and the elderly group (*p*<0.05) and the young group (*p*<0.001) were significant. The ROSvFD2-D was 1.28±0.37 in the young group, 1.52±0.17 in the elderly group, and 1.83±0.23 in the fall group.

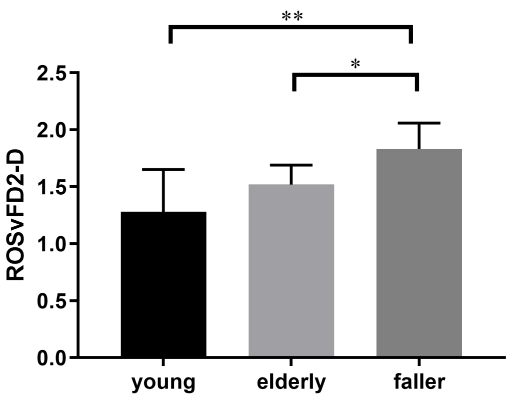

Fig. 2 ROSvFD2-D in each group with the increase of obstacle height. (*p< 0.05, **p< 0.001).

Similar to the results of ROSvFD2-D, ROSvIP2-D in the fall group was also significantly higher than that in the young and elderly groups (*p*<0.05), as seen in Fig. 3. ROSvIP2-D was 0.20±0.42 in the younger group, 0.10±0.32 in the older group, and 0.80±0.42 in the fall group.

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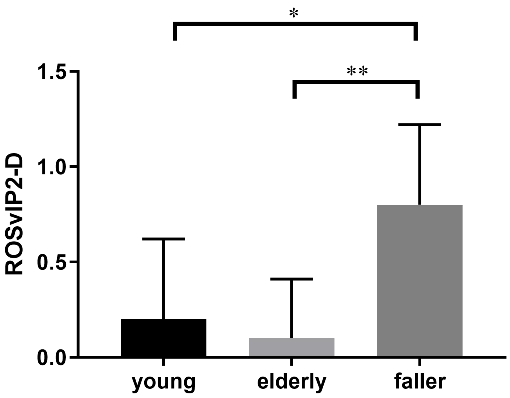

Fig. 3 ROSvIP2-D in each group with the increase of obstacle height. (*p< 0.05, **p< 0.001).

ROSvSE2-D increased with age and tripping history (Fig. 4). The ROSvSE2-D in the young group (4.19±1.72) was significantly lower than that in the elderly group (4.74±0.78, p<0.001) and the fall group (6.40±1.44, p<0.05), and there was also a statistically significant difference between the elderly group and the fall group (p<0.001).

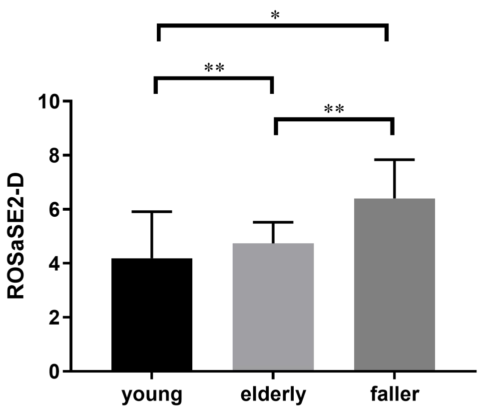

Fig. 4 ROSvSE2-D in each group with the increase of obstacle height. (*p< 0.05, **p< 0.001).

5. Discussion

In this study, a continuous random obstacle experimental environment was built, that is, obstacles of different heights were randomly set up on a straight walk. The kinematic data of different people continuously crossing random obstacles were collected, and the traditional kinematic parameters, temporal dynamic stability domain parameters, and other parameters that could express the dynamic stability control ability of continuous gait to different degrees were calculated. To finely quantify the dynamic stability control ability of different people when they cross obstacles.

The traditional kinematic parameters express the decline of dynamic stability caused by aging to a certain extent. There was a significant trend for TOD to increase with age. With the increase of age, the elderly will have more or less functional degradation and decreased perception ability [15]. At the same time, studies have shown that older people need a longer time to react and cross obstacles when they encounter obstacles, which also leads to their relatively low success rate of crossing obstacles [16]. The significant increase in TOD in the present study may be related to the expectation that older adults when faced with successive obstacles, will reserve sufficient time for smooth crossing by stepping ahead. In addition, HOD tended to increase with age. Considering that the TOD of the older group was also larger than that of the younger group, it may be related to the larger hip and knee angles of the older subjects across the legs [17]. In addition, generally speaking, the step length of the elderly is much smaller than that of the young due to the decline of muscle

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strength levels and the weakening of joint mobility [18]. The significant increase in HOD and TOD may place higher demands on the musculoskeletal system, and it may be more difficult for elderly people with degeneration to maintain dynamic stability when crossing obstacles, which may lead to trips. The TOC did not show a trend of change with age, indicating that the ability of the young group to self-adjust step height with obstacle height may also be decreased in the trail environment with random height obstacles. However, the above traditional kinematic parameters showed detailed differences between the fall group and the elderly group, which was consistent with previous studies [19].

The temporal dynamic stability parameter calculates the data of the complete obstacle-crossing movement, which may provide more information for the analysis of the obstacle-crossing gait of different dynamic stability groups. The 2-D ROSv results based on the Fréchet distance showed that the difference between the receiver and the standard curve would increase significantly with age. Since the standard curve represents the situation in which the human body maintains dynamic stability in a single support phase, based on the results of ROSvFD2-D, we learned that the dynamic stability of gait across obstacles has already decreased significantly in the elderly compared with the young. It is noteworthy that ROSvFD2-D parameters showed significant differences between the fall group and the elderly group, while the traditional kinematic parameters could not express the detailed differences in dynamic stability between the fall group and the elderly group. That is, this parameter may be more suitable for analyzing subtle differences in dynamic stability control ability in older adults due to tripping.

Similar results were obtained for the ROSv instability probability parameter. The probability of ROSv instability increases significantly with age and the occurrence of tripping history in the elderly. That is, in the process of crossing the obstacle, the ratio of the displacement beyond the stability boundary to the total displacement of the subjects in the fall group was larger, and they were more prone to instability. Although the fall group was also able to successfully overcome obstacles of different heights in the process of obstacle-crossing gait data collection, their muscle strength was significantly lower than that of young people, so the demand for muscles was relatively higher, and the potential consequences of muscle fatigue during exercise may increase the risk of trips of subjects in the fall group [20].

Similarly, the two-dimensional ROSa Shannon entropy parameter can not only reflect the difference in dynamic stability caused by aging and tripping history but also is more sensitive than the other two dynamic stability parameters, which may be related to the physical meaning of the parameter itself. The acceleration index can not only reflect the influence degree of different momentum control abilities on dynamic stability more sensitiveness but also reveal the mechanism of the elderly who are prone to fall while walking due to the decline of skeletal muscle control ability. In addition, Shannon entropy can also be used to express the degree of uncertainty or chaos more precisely. When the two parameters were superimposed, the sensitivity of ROSaSE2-D parameters was greatly improved.

In conclusion, the dynamic stability analysis results for different groups of people continuously crossing obstacles of different heights show that the kinematic parameters can significantly reflect the changes in dynamic stability caused by aging, and the temporal dynamic stability parameters can accurately distinguish the differences in dynamic stability caused by trip-history on this basis. The study of the dynamic stability of a single support phase based on temporal parameters no longer assumes a certain moment as a risk moment but takes the complete single support phase as the research object to analyze the gait stability of the subjects, which reduces the problem of missing information and improves the accuracy of the dynamic stability analysis of crossing obstacles. This study only analyzed the kinematic data of different subjects during continuous gait across random obstacles. In the future, kinetic data and electromyography data can be supplemented for data fusion analysis to further improve the dynamic stability analysis method.

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