A Review of the Stability of the Lower Limbs During the Human Locomotion

TANG Hai-peng*1 • TOYOSHIMA Shintaro*2 • DENG Xiu*3

1 Introduction

Unevenness always exists during human locomotion, therefore it is difficult to repeat the same movement exactly each time. Such unevenness can be observed not only in the inexperienced movement, but also in the reaching movement performed by arms, as well as in the movements of walking or running performed by the lower limbs. Such kind of unevenness in movement is regarded to be the stability of motion.

There have been studies about the stability of motion in the reaching movement between two points of the arm[4,11], and the stability of motion in a standing posture with unsteady central gravity in the lower limbs[12]. The stability of motion discussed in this report will focus on the stability of movement of the lower limbs which creates human locomotion such as walking and running. This stability of motion is considered to be influenced by individual genes, exercise experiences, sex, muscular strength, aging and changing movement speed. Furthermore, instability of motion can also be observed due to fatigue or during starting movements.

Since the elements of human movement are composed of both space and time, there is unevenness of space and time in human locomotion. Therefore unevenness of length and time in each step and pitch can be observed all the time, even in the most frequent occurring daily repeated locomotion with high accuracy like walking and running. Thus this unevenness both in space and time can be regarded to be unevenness of spatial stability and time stability.

In order to secure the safety in daily life locomotion, stability of the lower limbs is necessary. It is well known that the risk of falling down becomes higher when people are getting older, which is generally considered to be the result of declining of muscular strength of the elderly[8]. But on the other hand, it can also be regarded as the result of a decline of motion stability while people are aging[19]. High motion stability is also required in sport activities like kicking a ball or stepping on a takeoff accurately, thus the improvement of stability can be regarded as an important part of the improvement of technique.

As described above, the improvement of stability had a great influence over the locomotion of the lower limbs both in daily life

and in sport activities. Therefore studies concerning about motion stability are needed. But up to now only few reports have focused on this field. In this report, a review study will be conducted by exploring how motion stability is related to the elements of aging, sex, muscular strength etc., during activities such as walking, running or high-speed stepping motion. The ultimate goal of this study is to illuminate the way for further studies in the field of motion stability in lower limbs.

2 Coefficient Variation for the Evaluation of Stability

Current studies relative to the stability of lower limbs in walking and running were carried out by quantitative evaluation for the motion stability based on the coefficient of variation (CV) . The CV was calculated on the ratio of standard deviation to the mean[6,9,19] .

CV=SD/X *100

SD and X are the measurements of standard deviation and means.

A study about motion stability by Tang[19] and colleagues was conducted by examining 80 subjects ranging from teenagers to the elderly, both male and female, without orthopedic diseases. In order to evaluate the influence on motion stability by the process of aging, a wide range of age groups of subjects was assessed. Furthermore, to examine sexual differences of the motion stability, approximately the same number of male and female subjects was tested. The test was conducted in high-speed stationary stepping motion for 15 seconds. Each subject was videotaped with a video camera operating at 60Hz set about 10m in front. The peak height values that the knee joint reached at each step were digitized. Both the pitch time of the joint reaching to the peak point in each time, and the total number of times of the joint reaching to the peak were calculated for 15 seconds from the digitized data.

3 Instability of Motion in the Starting and Fatigue Periods of Sports Activities

Instability of motion can be often observed at the starting period of sport activities and games. Particularly in baseball game, it is common for athletes to experience a period of disorder and instability in the very beginning. Therefore, it is suggested that athletes should pay special attention in ball pitching in the starting period[1,7] . Of course, instability of motion also appears in the starting period in many other ballgames as well, such as golf, soccer, badminton and so on. Moreover, instability of motion can also be caused by fatigue accumulated during sport activities. As a result, unevenness of movement often increases, and, for example, the form of athletes often deteriorates in the latter half of races such as running or walking races in track-and-field[2].

In Tang' s study[20] , instability during the starting period was observed in most of the male subjects by analyzing measurement results of high speed stationary stepping motion. So far, this kind of instability has been explained as the result of psychological factors. But according to the results of this study, instability in the starting period can also be considered to be one of the body features of middle-aged and older males while doing exercise. Thus it might be necessary to develop new training methods with consideration of this different point of view.

In the same test[20] , instability was observed in most of the male and female subjects in the ending period of stepping motion.

This phenomenon can be explained to be the cause of fatigue as many reports have already suggested. This kind of instability can be considered as the result of declining of muscle functional balance[12] and muscle active strength caused by fatigue[3] .

4 Motion Speed and Stability

It is generally supposed that when motion speed increases, movement is likely to become disordered, at the same time, unevenness occurs on a bigger scale. In spite of that, a different factor was found from the study of the following measurements. Measurements[20] were taken of the perpendicular displacements in the knees in two types of walking(free walking and fast walking), and two types of running (jogging and scampering) . The CV of walk with the slowest speed was the highest, and motion stability was low as well. On the other hand when the speed increased, the CV decreased, and motion stability improved simultaneously. This phenomenon can be explained as a basic body function to increase stability for self-protection from movement disorder or falling down. Because when the speed increases, at the same time the risk from exercise increases, therefore even a bit of disorder might have a big influence on exercise rhythm, which might cause an accident by falling.

5 Spatial Stability

5.1 Stability of Walking

The study by Ishii[6] analyzed the measurement result of length and time for each step in 20 steps. The steps were required for three speeds, slow, normal and fast. The subjects were 19 young people and 19 elderly people, respectively. A comparative study of the stability of walking between the young and the elderly groups was conducted by examining the CV which calculated the mean and standard deviation of walking speed, step length and time.

The result[6] also showed that the value of CV of step length of the elderly was higher than the young subjects group in every step, and the same tendency was reported from slow speed to fast speed. For the young subject group, the CV kept low and the stability showed almost no change even when their walking speed increased. In contrast, for the elderly subject group, low value of CV of step length existed in a narrow range of walking speed, and their consistency of walking had lower variation than the young subject group.

5.2 Stability and Sex Differences

It was reported[19] that for the high-speed stationary stepping motion, the teenager group of males and the middle-aged group of females appeared to have better stability. According to Tang' s study[19] , the sex differences of the stability of motion was not influenced by the maximum muscular strength, but influenced by the level of activity standard in daily life, and influenced by people' s physical adjustment ability as well.

Concerning about the activity ability of the muscles, some researchers[15] suggested that females had a higher activity ability than males in the lower limbs in supporting the body weight and moving around in daily lives. It was supposed that because females generally had shorter lower limbs compared with males.

Hence, it can be suggested that a lot of muscle activity by females in daily lives contributed to their stability of motion. Similarly, generally boys had more physical movements

than girls, therefore, male teenagers improved a better stability of motion than female teenagers[14] . On the other hand, in the oldest-old group, males appeared to have a better stability of motion than females, which was considered to be the result of weaker muscular strength of the oldest-old females.

5.3 Stability and Aging

With respect to age, according to Tang' s report[19] , the CV of the teenager group was bigger than the youth and middle-aged groups, and also the CV of the elderly group appeared to be much bigger than all the other groups. This instability of teenagers was due to their non-mature body development, which also accounted for the unevenness in their movements.

The stability of movement in youth and middle-aged groups kept stable for a long period of time because of the maturity of their body development. After middle age, the stability of movement began to decline because of the declining of body functions during aging. Furthermore, big individual differences of stability of CV were observed within the elderly group which showed that even in the same age group, big individual differences of stability existed among the elderly[16,17,18] .

Based on the phenomenon proved by the study that stability greatly declined from 70 years old, 70 years old was considered to be the starting point of the decline of motion stability[5] . Moreover, it was reported that walking speeds began to slow down from approximately 62 years old. According to these phenomena, a certain age can be considered as the starting point of the rapid decline of motion stability and walking speeds. Although up to now the cause has not been defined relative to this rapid changing at a certain age, yet this still can be a piece of basic and important information for the improvement of methods on how to maintain the body movement function as well as how to develop the training programs for the elderly.

It was pointed out that the main causes of falling down of the elderly were due to the declining of muscular strength in lower limbs, as well as the low swing ability during their movements[8] . Because of the decline of stability, the possibility of uneven and unbalanced situations increase. during quick movements, which was suggested to be related to the falling down in the fast walking or running of the elderly.

5.4 The Influence of Muscular Strength

The study[19] also found that the stability of motion began to decline when muscular strength was lower than 17 kg for males and 9 kg for females. In other words, muscular strength lower than 17 kg for males and 9 kg for females was the critical values in changing the stability of motion. When the values of muscular strength were higher than these critical values, the stability of motion was hardly influenced by muscular strength. On the other hand, the stability was more likely to decline when the values of muscular strength were lower than critical values.

The study conducted by Sunata[12] research group provided the cause in influence of the spatial stability of motion. The study was carried out by measuring the unsteadiness of central gravity in a vertical posture. It proved that the stability of the standing posture was influenced by the functional unbalanced state owing to the fatigue of antigravity muscles. Another study conducted by Fukita[3] research group examined the dynamic stability of ankle joint influenced by the fatigue of

muscle around it. The EMC of muscle fatigue of ankle joint was measured both before and after exercise. The result showed that the dynamic stability of ankle joint was affected by the decline of the muscle activities of long fibula muscle caused by its fatigue.

6 Time Stability

6.1 Stability of Walking

Concerning time stability, the study by Maruyama[10] et al examined the CV of walking time, as well as the correlation between the walking speed and walking rates, by analyzing treadmill walking conducted by 7 male adults. The walking speeds were 2,3,4,5,6km/h, the walking rates were 60, 80, 100, 120, 140, 160 steps/min. The meaningful main effect in the walk rate of the subjects was recognized in the CV of all the aspects. And CV of the variation range was the biggest when supported by both legs. Within the walking speed range of 2-5km/h, the slower the speed was, the smaller the CV of the period supported by both legs would be. The walking rate was reported to be the lowest in free walking while keeping a certain speed.

6.2 The Influences of Aging and Muscular Strength

It was reported that there were no any significant differences in time stability among all the different age groups both for male and female[20] . In other words, the time stability kept unchanged in spite of aging, while the spatial stability declined together with the decline of the body functions due to aging. This result suggested that instead of spatial stability, the human body system chose to keep time stability, which is considered more important for the elderly in preventing the loss of body balance in movements.

There have been a lot of studies[9] about the big influences in body movement of muscular strength, yet the previous study proved that time stability is not influenced by changes of muscular strength. The time stability of movement is hardly related to muscular strength, but strongly affected mainly by the nervous system and control system of human body.

6.3 A Comparative Analysis of Spatial Stability and Time Stability

Physical movement is generally composed of time elements and space elements. According to Tang' s research[20] , the value of CV of space was bigger than the value of time. For the teenager group, its value appears to be three times bigger than for the middle-aged group, and about four times bigger than the elderly group. Furthermore, significant differences were recognized in all age groups. Compared with CV of spatial stability, the superiority of time stability is obvious in high-speed movement.

The study conducted by Tang et al[20] also proved that, compared with the permitted limit of time unevenness, the permitted limit of spatial unevenness appears much wider. With other expression, the movement can be performed in spite of big step unevenness, but the loss of balance might occur with a big pitch unevenness during fast walking or running. Whereas it can be concluded that during walking or running, the step length can be adjusted and improved in a wider range compared with pitch.

Many studies have demonstrated that the step length increases together with the body development and scamper speed improvement during the development of scamper movement from an infant to an adult[13] . But

as for the pitch, the increase is not as big as the step length. The reported has also shown that the decline of walking movement of the elderly was due to the decline of their step length. Compared with the decline of pitch (10%), the decline of step length was proved to be much bigger (25%)[8]. Therefore, it should be more efficient to improve the step length than the pitch, based on the result of improvement of training programs for free and fast walking of the elderly.

According to the previous studies, compared with spatial element of movement, the time element is improved to be more consistent. Therefore, the influence of the time element is quite limited, it is not much influenced by the improvement of training programs, nor influenced by the body decline becouse of aging. Such a characteristic of spatial stability and time stability can be regarded as one of the important basic characteristics of human physical movement.

7 The Prospects of the Stability study

According to this review study, there have been some reports about the stability in walking and stepping movements, but there have been still few reports about the stability in running movements. Also, there have been few reports about motion stability in running, kicking and taking-off from lower limbs as well. We hope that this review can light the way leading to studies related the above fields of research.

Notes

*1 Professor of the Aichi Prefectural University
*2 Professor of the Tokaigakuen University
*3 Professor of the Hyogo University

References

1) Eto S: Pitching perfect master. 新星出版社: Tokyo, 88, 2006
2) Fuchimoto T, et al.: Biomechanical analysis on 'slowing-down' during 400 m and 800 m runs. Proceeding of the Congress of Biomechanics of Japan 1988. 215-220.1989
3) Fukita S, et al.: 足関節周囲筋の疲労が関節の動的安定性に及ぼす影響について, Jpn. J Phys. Fitness Sport Med. 50: 996, 2001
4) Hareeis CM, et al.: Signal dependent noise determines motor planning. Nature, 394: 780-784, 1998
5) Himann JE, et al.: Age-related changes in speed of walking, Med. Sci. Sports Exec. 20: 161-166, 1988
6) Ishii E, et al.: 高齢者における歩幅の変動係数, Rigaku ryohogaku 27(2): 338, 2000
7) Ito E: 野球上達Book-Pitching-. 成美堂出版: Tokyo, 86, 2006
8) Kaneko M, et al.: Biomechanical analysis of walking and fitness testing in elderly women. In: Kaneko, M. (Eds), Fitness for the Aged, Disabled, and Industrial Worker, 84-89, Human Kinematics Publishers, 1990
9) Kim J, et al.: Relationship between reduction of hip joint and thigh muscle and walking ability in elderly people. Jpn. J Phys. Fitness Sport Med. 49: 589-596, 2000
10) Maruyama H, et al.: 歩行周期の各相に要する時間の変動係数－その速度と歩行率依存性. The Japanese Journal of Rehabilitation Medicine, 26(4): 249, 1989
11) Oyama T, et al.: Analysis of variability of human reaching movements in consideration of similarity of arm trajectories. ITICE Technical Report NC 2005-156:

31-36, 2006

12) Sunada S, et al.: Effect of functional imbalance of anti-gravity muscles by sectional muscle fatigue.39: Bulletin of Research Institute of Health and Sport Sciences Chukyou University, 39(2): 103-109,1998

13) Saito M, et al.: Movement characteristics of leg action during spring running in girls, aged 2 to 10. Bulletin of Research Institute of Health and Sport Sciences Chukyou University, 22: 23-30, 1998

14) Saito Y : Relational between grading ability on ball throwing and physical fitness and constitution. Journal of the Faculty of Education and Human Sciences, Yokohama National University, 9: 93-100, 1970

15) Sawai S., et al.: Sexual-related difference in the lever of muscular activity of trunk and lower limb during basic daily life action. Jpn. J Phys. Fitness Sport Med. 55: 247-258, 2006

16) Tang HP, et al.: Characteristics in walking kinematics of elderly before one year of death. Journal of Society of Biomechanisms, 26: 40-44, 2002

17) Tang HP, et al.: 階段昇降トレーニングが歩行能力に及ぼす影響. Journal of Health, Physical Education and Recreation. 65: 748-752, 2006

18) Tang HP, et al.: An eight-year follow-up study of walking movement in elderly. Journal of Society of Biomechanisms, 31: 51-55, 2007

19) Tang HP, et al.: The stability of the lower limbs during the high speed motion. Journal of Society of Biomechanisms, 34: 333-338, 2010

20) Tang HP: ANTI-AGING series No. 4, NTS: Tokyo, 158-164, 2014