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Comparison of Motion Strategies in the Functional Reach Test between Elderly Persons and Young Persons

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Abstract. [Purpose] Evaluation of motion strategy during FRT is not generally included in physical assessment aiming at rehabilitation and promotion of good health. We believe that measuring only reach distance during FRT is insufficient for evaluating gait; therefore, examining motion strategy during FRT is also necessary. [Subjects] The subjects were 83 healthy university students (46 men and 37 women; range, 19–21 years), and 128 elderly persons (42 men and 86 women; range, 70–87 years). [Methods] We investigated and compared the motion strategy during FRT in both the young and elderly subjects and examined the influence of aging on motion strategy. [Results] Elderly persons used patterns of movement with ankle plantar flexion more often than the young persons. [Conclusion] The ankle plantar flexion pattern was dominant among the elderly subjects because the center of gravity in FRT was located within the base of support. We would like to use FRT as an index for fall prevention. To do that, we would need to devise a method to measure the ability to control the body in the situation in which center of gravity starts deviating from the base of support.
Key words: Functional reach test, Motion strategy pattern, Risk of falling

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INTRODUCTION

The functional reach test (FRT) is widely used to evaluate a subject's degree of balance in the standing position. Oofuchi et al.[1] and Arai et al.[2] reported that the motion strategy used to prevent falling improved the reach distance of elderly subjects in FRT. These reports suggest that FRT is an important test for evaluating balance. On the other hand, Suzuki et al.[3] and Kin et al.[4] reported that the difference in reach distance between fallers and non-fallers was not significant. In other words, the relationship between reach distance and risk of falling is not clear and a longer reach distance is not necessarily related to risk of a fall. However, it has been reported that a change in the motion strategy employed during FRT was reflected subjects' gait patterns. Yoshida et al.[5] also reported that the motion strategy observed during FRT influenced the gait ability of patients with subacute myelo-optic neuropathy (SMON) for 5 years. In their report, it is mentioned that gait pattern was related to motion strategy, not reach distance in FRT. Both reach distance and motion strategy in FRT have been suggested to be important when the test is used for gait analysis; however, evaluation of motion strategy during FRT is not generally included in physical assessment when aiming at rehabilitation and promotion of good health. In addition, there is no one standardized method or index of assessing motion strategy during FRT. We believe that measuring only reach distance during FRT is insufficient for evaluating gait; therefore, examining motion strategy during FRT is also necessary. We investigated and compared the motion strategy during FRT in both young and elderly subjects, as basic research, and examined the influence of aging on motion strategy. Our objective was to analyze the characteristics of the motion strategy pattern in FRT with aging and the relationship between motion strategy pattern in FRT and the balance function of standing and the gait.

SUBJECTS AND METHODS

This study was approved by the ethical committee of Kansai University of health sciences. The study procedures, risks, and benefits were explained to all participants. The younger group was comprised of 83 healthy university students (46 men and 37 women; range, 19–21 years), and the elder group was comprised of 128 elderly persons (42 men and 86 women; range, 70–87 years). We evaluated FRT and analyzed the movement patterns of both groups. FRT was performed using the "yardstick" method reported by Duncan et al[6]. The method was as follows: The subject stood next to the functional reach measurement device, extended one arm horizontally at approximately 90°, and placed a closed fist against the sliding bar of the device. Subjects were asked to move the sliding bar as far forward as possible (Fig. 1). Each subject was given two practice trials and three test trials, as described by Duncan et al. and the results of the three test trials were analyzed. To investigate motion strategy during FRT, the movements of the subjects were recorded in the sagittal plane using a digital video camera (Xacti SANYO, Japan) and an image capture rate of 60 frames par second. The order of joint movement was analyzed using the pictures recorded by the camera. Movement strategy patterns during FRT were determined by two physical therapists and classified into distinct patterns. The strategy patterns were classified in the order of the appearance of joint movement. Patterns were classified for all the trials for each subject and the ratio of the number of each pattern to the number of trials was compared between the younger and elder groups. In addition, we examined the relation between the movement strategy pattern and reach distance. Reach distances for each movement strategy pattern were compared using the Kruskal–Wallis test and Scheffé's post hoc test to rank the patterns in the younger and elder groups. Statistical analyses were performed using Harubou ver.7.

RESULTS

Movement strategy patterns used by both the younger and elder groups were as follows.

In the elder group, hip flexion followed by ankle plantarflexion (HP pattern, 55.5% of all trials) was the dominant movement strategy. The following patterns were also observed: only hip flexion (H pattern, 30.5%); hip flexion with ankle plantarflexion (H/P pattern, 4.9%); ankle dorsiflexion followed by hip flexion (DH pattern, 4.4%); ankle dorsiflexion followed by hip flexion and ankle plantarflexion (DHP pattern, 1.8%); hip flexion followed by ankle dorsiflexion (HD pattern, 1.5%); hip flexion with ankle dorsiflexion (H/D pattern, 0.8%); and hip flexion followed by ankle dorsiflexion and ankle plantarflexion (HDP pattern, 0.5%) .

In the younger group, hip flexion alone (H pattern, 42.6%) was the dominant movement strategy. The following patterns were also observed: ankle dorsiflexion followed by hip flexion (DH pattern, 37.3%); hip flexion followed by ankle plantarflexion (HP pattern, 10.8%); ankle dorsiflexion alone (D pattern, 5.6%); hip flexion with ankle plantarflexion (H/P pattern, 1.6%); hip flexion followed by ankle dorsiflexion (HD pattern, 1.2%); and hip flexion with ankle dorsiflexion (D/H pattern, 0.4%). Neither the DHP nor the HDP pattern was observed among the strategy patterns employed by the younger group. In addition, the D pattern was not demonstrated in the elder group but was demonstrated in younger group.

The mean reach distances of the four frequently- used patterns in the elder group were: 1) 33.5 ± 5.0 cm for the HP pattern, 2) 29.5 ± 4.8 cm for the H pattern, 3) 32.9 ± 5.8 cm for the H/P pattern, and 4) 28.9 ± 5.1 cm for the DH pattern. The reach distances of the HP pattern were significantly longer than those of the H and DH patterns in the pairwise comparison (1–2: p<0.01, 1–4: p<0.01) (Table 1).

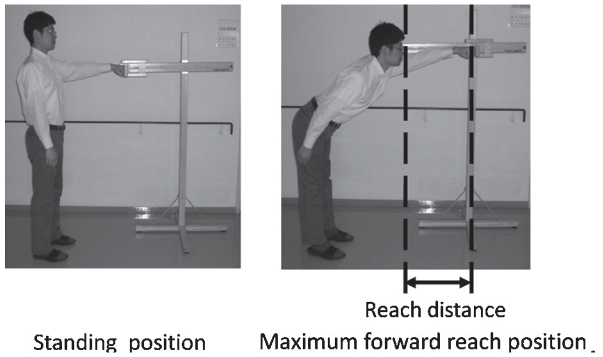

Fig. 1. Functional reach test
The subjects stood next to the functional reach measurement device with one arm extended horizontally at approximately 90°and placed a closed fist against the sliding bar of the device. Subjects were asked to move the sliding bar reaching as far forward as possible without taking a step.

In addition, the mean reach distances of the four frequently- used patterns in the younger group were: 1) 35.8 ± 6.9 cm for the H pattern, 2) 36.4 ± 7.0 cm for the DH pattern, 3) 32.7 ± 7.4 cm for the HP pattern, and 4) 24.8 ± 4.8 cm for the D pattern. Reach distances of the H, DH, and HP patterns were significantly longer than that of the D pattern, but there were no significant differences among the H, DH, and HP patterns in the pairwise comparison (1–4: p<0.01, 2–4: p<0.01, 3–4: p<0.05) (Table 2).

DISCUSSION

In standing, stability is good when the center of gravity is near the center of the base of support; however, it is easy to fall when the center of gravity is near the edge of the base of support[7]. FRT involves a voluntary motion of reaching forward with a fixed base of support and controlling weight transfer without changing the base of support is important Reach distance during FRT has been used as an index to assess fall risk. However we believe that a fall is related to the position of the center of gravity and its relation to the support base; It is very important to examine the change in joint motion relative to the movement of the center of gravity.

In this study, FRT was performed by both the elder and younger groups, and we analyzed the motion strategy used during the test. We found eight motion strategy patterns in the elder group and seven motion strategy patterns in the younger group. The HP pattern was most frequently used in the elder group. In this pattern, the subject's center of gravity is displaced forward on the base of support as the trunk bends forward with initial hip flexion and the center of gravity return to its original position when the lower limbs bent backwards during ankle plantarflexion. Consequently, the posture remains steady as the subject's

Table 1. Relation between reach distances and movement strategy pattern in the elder group

	1.HP	2.H	3.H/P	4.DH
The mean of reach distance	33.5 (5.0)	29.5 (4.8)	32.9 (5.8)	28.9 (5.1)

Upper values are the mean reach distance (cm) and lower values are the SD. Reach distance of the HP pattern was significantly longer than those of the H and DH patterns in the pairwise comparison (1–2: $p<0.01$, 1–4: $p<0.01$).

Table 2. Relation between reach distances and movement strategy pattern in younger group

	1.H	2.DH	3.HP	4.D
The mean of reach distance	35.8 (6.9)	36.4 (7.0)	32.7 (7.4)	24.8 (4.8)

Upper values are the mean reach distance (cm) and lower values are the SD. Reach distances of the H, DH and HP patterns were significantly longer than that of the D pattern, but there were no significant differences among the H , DH and HP patterns in the pairwise comparison (1–4: $p<0.01$, 2–4: $p<0.01$, 3–4: $p<0.05$).

center of gravity approaches the center of the base of support. On the other hand, in the H pattern, the second highest in frequency, only the hip is used in flexion during FRT motion. The center of gravity returns to the center of the base of support when the lower limbs bend backwards during ankle plantarflexion. As a result, the subject's center of gravity approaches the center of the base of support and the subjects' posture remains steady. This pattern differs from the HP pattern in that it does not return the center of gravity backward by plantar flexion of the ankle. The forward weight shift is controlled by a strong contraction of ankle plantarflexors, allowing the reach to be extended without falling.

Standing balance is controlled during turbulence by movements of the ankle and hip joints, classified as "ankle strategy" and "hip strategy", respectively. It is reported that the ankle strategy is dominant when the center of gravity is located near the center of the base of support, but the importance of the hip strategy increases when the center of gravity is displaced from the base of support[8)]. It is also reported that the hip strategy is used in balance reaction to rapid turbulence, taking priority over ankle strategy. It moves the upper part of the trunk and the lower limbs in opposite directions, thereby reducing the change in the center of gravity and realigning it with the center of the base of support. The HP pattern seen in the elder group is a strategy that causes a backward bend in the legs with ankle plantarflexion following a forward bend in the trunk with hip flexion, and we believe that the HP pattern uses the hip strategy. When the displacement of the center of gravity from the base of support is minimal, the hip strategy is used. We think this strategy is used by persons who cannot positively displace the center of gravity forward from the center of the base of support. The H pattern uses the hip strategy just as the HP pattern; however, it is different from the HP pattern in that the FRT motion is achieved only by bending the trunk forward with hip flexion. The forward displacement of the center of gravity during FRT motion is achieved through hip flexion without using ankle plantarflexion; therefore, the displacement of the center of gravity forward from the base of support is larger than in the HP pattern and more difficult. We presume that persons who use the H pattern have greater motor control than persons who use the HP pattern.

In the H/P pattern, the lower legs are tilted backward by ankle plantarflexion and the trunk is tilted forward by hip flexion. This pattern appears simultaneously with the onset of FRT motion. Unlike the HP pattern, it returns the center of gravity to the center of the base of support by ankle plantarflexion after first displacing the center of gravity by hip flexion. We believe that the H/P pattern always maintains the center of gravity at the center of the base of support by simultaneous hip flexion and ankle plantarflexion. This strategy attempts to maintain stability using ankle plantarflexion when it is difficult to control the forward displacement of the center of gravity with only hip flexion and the strong muscles of the lower limbs.

The DH pattern tilts the trunk further forward during hip flexion after the entire body has been tilted forward by ankle dorsiflexion. We believe that this pattern displaces the center of gravity forward by tilting the entire body. Tilting of the entire body is controlled by the eccentric contraction of the surrounding muscles of the lower limbs and the ankle plantarflexors. After this movement, the center of gravity is moved forward by hip flexion and the reach is extended. This pattern differs from the others in that it is a motion strategy that uses ankle dorsiflexion in the first phase of FRT motion.

We believe that ankle strategy is used when there is little movement of the center of gravity. In other words, the ankle strategy posed little difficulty to the subjects in the elder group who used this strategy, suggesting that subjects who use this pattern have greater motor control than who use the HP or H patterns.

In the DHP pattern, ankle plantarflexion tilts the lower legs backward to bring the center of gravity close to the center of the base of support in the final phase of FRT motion when it cannot stop the forward transfer of the center of gravity in the DH pattern. This pattern resembles the H pattern in that it maintains stability after the lower leg have been tilted backward by ankle plantarflexion.

In the HD pattern, the order of events of the DH pattern are reversed. During the HD pattern, the center of gravity moves forward at the onset of FRT motion as the trunk is tilted forward by hip flexion. After this movement, we believe that ankle dorsiflexion moves the center of gravity further forward extending the reach. The D/H pattern is the same as the DH or HD pattern except that hip flexion and ankle dorsiflexion are simultaneous.

During the HDP pattern, ankle plantarflexion brings the center of gravity closer to the center of the base of support by tilting the lower limbs backward in the final phase of the FRT motion when the forward weight transfer in the HD pattern cannot be stopped. With these patterns, We believe that a stronger contraction of plantarflexors of the ankle joint is needed to control ankle dorsiflexion after the center of gravity moves forward under hip flexion. The above-mentioned patterns were used by subjects in the elder group. Neither the DHP nor the HDP pattern was used by subjects in the younger group; the D pattern was seen instead. The D pattern is an ankle only dorsiflexion movement. We believe that this pattern keeps the center of gravity to the center at the base of support using only contraction of the muscles surrounding the foot joint, e.g. the plantarflexion muscle group, while the entire body tilts forward from the thigh downward in forward reach.

In the present study, we did not limit the motion strategies of the subjects. The HP pattern was dominant among the elderly subjects because the center of gravity in FRT was located within the base of support. We would like to use FRT as an index for fall prevention. To do that, we would need to devise a method to measure the ability to control the body in the situation in which center of gravity starts deviating from the base of support. When thinking about FRT in these terms, we consider a method that limits plantarflexion of the ankle as much as possible is needed.

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