1.1 Stroke and rehabilitation

Stroke is a major disease worldwide. It is a type of cardiovascular disease. It affects the arteries leading to and within the brain as a result of an obstruction within a blood vessel (ischemic stroke) or rupture of a blood vessel (hemorrhagic stroke). It is the third most common cause of death in the UK and USA (The Stroke Association, UK, 2008 & American Heart Association, 2008). It is also a leading cause of severe adult disability.

Similarly, in Hong Kong, statistics report of the Hospital Authority in 2006/2007 showed that there were total 25991 incidences of stroke in the year of 2006 and the mortality rate was 12.7%. It is one of the major disease cause of hospital admission and fourth cause of death in that year. A common disability that results from stroke is paralysis on one side of the body, called hemiplegia. Moreover, impaired sensation, co-ordination and increased or decreased muscle tone of the limbs are also common in stroke patients. Besides these physical problems, stroke may also cause problems with thinking, awareness, attention, learning, judgment, memory, understanding or forming speech and leading to emotional, psychological and social problems. Therefore, a multidisciplinary rehabilitation programme for stroke survivors is very important.
For physiotherapists, intensive training including muscle strengthening exercise, sensory re-training, soft tissue stretching, tone normalization exercise, co-ordination training, standing balance and gait re-education are important to stroke survivors. Among most of the stroke survivors, impaired walking causes a certain degree of functional disability. Thus, to restore patients’ walking independency then to resume their daily activities and hence improve their quality of life is the ultimate goal in stroke rehabilitation. Fortunately, research has shown more than 75% of stroke survivors (632 out of 804 patients) can eventually walk independently or walk with assistance within the first 11 weeks after stroke rehabilitation (Jørgensen, Nakayama, Raaschou & Olsen 1995). Therefore, intensive gait re-education to this group of stroke survivors to restore a normal gait is important. In fact, most of the physiotherapists using different techniques and spent a lot of time in gait re-education to encourage individual to load their paretic limb and increase the ability in using their paretic limb to facilitate a more normal gait pattern.

1.2 Normal gait

Normal gait is a complex activity which can be defined as the rhythmic, smooth and symmetrical alternating movements of the two lower extremities which result in the forward movement of the body. Simply stated, it is the manner in which we walk. The common terminology of gait includes temporal and spatial components. The temporal component (swing, stance, step and stride times) relates to periods of time
which events takes place and the spatial component (joint angles, step and stride lengths) refers to the angles moved and distances covered by the limbs in walking. The details are illustrated and described in figure 1, figure 2 and table 1.

**Figure 1.** Terminology and timing of the gait cycle. (Adopted from Trew & Everett, 1997)

**Figure 2.** Spatial parameters of gait can be measured from foot prints.

(Modified from Trew & Everett, 1997)
**Table 1: Definition of terminology of gait**

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
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<tr>
<td>Gait cycle</td>
<td>This is the period of time during which a complete sequence of events takes place. It is usually refers to the time between heel strike of one limb (reference limb) and the subsequent heel strike of that same limb. The gait cycle is subdivided into a stance phase and a swing phase.</td>
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<tr>
<td>Swing phase</td>
<td>This is the period of time of one limb which is not in contact with the floor.</td>
</tr>
<tr>
<td>Stance phase</td>
<td>This is the period of time of one limb which is in contact with the floor. It is subdivided into single stance phase and double stance phase.</td>
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<tr>
<td>Single stance phase</td>
<td>This is the period of time when only one foot is in contact with the floor. It equals to the swing phase of the other limb in walking</td>
</tr>
<tr>
<td>Double stance phase</td>
<td>This is the period of time when both feet are in contact with the ground simultaneously.</td>
</tr>
<tr>
<td>Strike length</td>
<td>This is the distance from initial contact of one foot to the following initial contact of the same foot</td>
</tr>
<tr>
<td>Step length</td>
<td>This is the distance between successive foot-foot contacts with</td>
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As refer to figure 1, normal walking is a repetition of the gait cycle. Gait cycle includes stance and swing phase. The stance phase can be subdivided into heel strike, foot flat, mid-stance and push off. Heel strike is the initial heel contact of the leading foot with the floor. At this moment, another foot is also in contact with the floor, results in a double stance phase. This is the moment the person is at his/her most stable position. Foot flat is the moment the whole foot is in contact with the floor and is followed rapidly by the mid-stance phase. In mid-stance, the body is carried forward over the stance limb and the opposite limb is in swing phase. At this moment, the whole-body weight is supported by the stance limb and this is the most unstable position during the gait cycle. Then it will progress to the push off stage. Push off is the stage during the stance phase when the heel leaves the ground to the moment of the toes leave the group and the swing phase starts.

The swing phase can be divided into acceleration, mid-swing and deceleration. The acceleration is the moment the non-weight bearing limb accelerates forwards. The mid-swing corresponds with the mid-stance and at this moment the limb swings through the stance limb. The deceleration is the final stage of the swing phase where the swing limb decelerates to prepare for another gait cycle to start (Trew & Everett, 1997 and Ayyappa, 1997).

Roth, Merbitz, Mroczek Dugan & Suh stated in 1997 that during normal
walking, both lower limbs bear weight equally, with equal time spent in single limb support. Each successive stance phase prepares the limb for the subsequent swing. In the late phase of stance, the body weight progresses forward, ready to be transferred onto the opposite swinging limb. Similarly, the swinging limb provides momentum to allow the progression of body weight forward. Normal gait tends to be symmetrical in temporal (between left and right swing, stance, step and strike times), spatial (between left and right joint angles, step and stride lengths as shown in figure 2) components and weight bearing of both lower limbs. The suggested difference between the two lower limbs in vertical force and temporal parameters is less than 6% (Kim & Eng 2003; Patterson et al 2008).

As refer to figure 1 above, in an average speed of normal walking in normal subjects, the stance phase takes about 60% of the time of the gait cycle while the swing phase takes about 40% (Trew & Everett, 1997). In slow walking, the stance phase can contribute more than 70% of the gait cycle and the swing phase is less than 30%. In fast walking, the stance phase may be decreased to less than 57% of the gait cycle. Moreover, the faster in walking, the less the time of the double stance phase. It varies from 46% to 14% of the gait cycle in slow walking to fast walking.

1.3 Hemiplegic gait

Hemiplegic gait has been frequently used by health care professionals to describe the slow, laborious and uncoordinated characteristics of gait pattern of
stroke patients. The hemiplegic gait patterns were well documented in many studies. Asymmetry was one of the most obvious features of the abnormal gait pattern in stroke patients. Titianova & Tarkka (1995) reported that chronic ambulatory hemiplegic patients walked more asymmetrically, swayed more laterally favoring their non-paretic leg and slower speed than matched healthy persons. This result was supported by Tyson (1999) who measured the lateral and vertical pelvic movements in walking with self-selected pace in a group of chronic stroke survivors who able to walk independently without a walking aid and found that mean lateral movement was large and orientated over the non-paretic side (6.4±3.9 centimeters) with little movement to the paretic side (1.2±4.3 centimeters). However, mean vertical displacement was relatively small with 1.4 ±0.9 centimeters on the paretic side and 3.4 ±1.1 centimeters on the non-paretic side. These results indicate decreased stance phase and weight bearing towards the paretic side.

Most recently, Patterson et al (2008) illustrated in their study that more than half (30 out of 50 participants) of the community-ambulating chronic stroke survivors, able to walk independently without supervision but could used walking aids, walked at their preferred, comfortable speed presented with temporal asymmetry. By comparison, fewer of them (18 out of 54) exhibited spatial step asymmetry. They also reported that there was significant variation in temporal symmetry values within this functionally homogeneous group of stroke survivors. The symmetry ratio ranged from within the normative range (0.9 to 1.1) to severely
asymmetric (4.52). Their result was consistent with previous studied of Wall & Turnbull (1986). They assessed the temporal asymmetry ratio in stance phase in 25 chronic stroke patients who walk with /without a walking aids and found that all subjects spent longer duration on the good limbs than the paretic limbs. Moreover, they also noted the symmetry ratio of single stance phase was much varied than the total stance phase (single stance plus double stance). Moreover, Patterson et al (2008) also suggested that the overall temporal symmetry value is superior to both swing and stance symmetry values as well as spatial symmetry values in discriminating among post-stroke ambulatory survivors.

Chen, Patten, Kothari & Zajac (2004) reported in their pilot study that consistent gait differences (increased percentage swing time and shortened support time on the paretic limb) existed between non-disabled controls and chronic stroke survivors who able to walk independently over ground with an ankle foot orthosis or an assistive device at matched speed.

Many years ago, Perry in 1969 (as cited in Kuan, Tsou & Su, 1999) observed hemiplegic gait and hypothesized that poor single limb balance and motor control of the paretic limb in forward progression resulted in the abnormal gait pattern of stroke patients. In 1987, Bohannon also reported that balance, weight-bearing ratio, motor control and normalized strength of the paretic lower limb was significant related to performance of hemiplegic gait. Recently, in 2005, Chen et al reported consistent findings. They found that inadequate strength of the hip, knee flexors and
ankle dorsiflexors of the paretic limb resulted in difficulty to propel the paretic leg in swing phase. This was compensated by raising the trunk during pre-swing and pelvic hiking during swing phase. Therefore, extra time and mechanical energy were used during swing phase. Reduced single limb support time was due to weakness and poor balance of the paretic limb.

Besides decreased single support time, Chen et al (2003) found that stroke patient with poor motor recovery spent 26 to 29% more time in double stance phase than single stance phase when compared with normal subjects. It was because poor stability of the paretic limb in single support phase encouraged the stroke patients take relatively smaller steps to minimize single-support time and quickly return to a more stable position, double stance phase. It means that stroke patients prefer to bear weight on the non-paretic limb because of insufficient stability of the paretic limb in single stance phase.

Von Schroeder, Coutts, Lyden, Billings & Nickel (1995) also reported that the paretic leg spent less time in single stance and more time in swing when compared with the non-paretic leg. Moreover, this asymmetrical gait pattern did not change for the first twelve months. Shorter stance phase, prolonged swing phase and decreased vertical ground reaction force (GRF) which provides information on weight bearing have also been reported on the paretic limb relative to the good limb in a group of chronic stroke patients who were able to walk independently without a walking aid (Kim & Eng 2003). Moreover, they also found that the temporal
asymmetry positively correlated with increased vertical GRF through the non-paretic limb. In addition, Marigold & Eng reported in 2006 that medial-lateral postural sway in static standing for 30s was compromised in individuals with chronic stroke and was significantly related to asymmetrical weight bearing. That means the more the weight put on the non-paretic limb, the more the postural sway.

Moreover, it is possible that the more weight-bearing asymmetry is accompanied by more severe the stroke-related impairments. They also proposed that mechanically unstable of the posture resulted in more weight stacked over one limb then lead to greater postural sway. It indicates that a more symmetrical weight bearing over both lower limbs will result in better postural stability. Therefore, it is why physiotherapist nowadays emphasizes a lot attention in weight shifting exercise in stroke patients to improve their weight bearing over the paretic limb to achieve a symmetrical and stable gait pattern.

Worthen et al (2005) found the mean vertical GRF of the paretic side was significantly lower than the non-paretic side in a group of chronic stroke patients (post stroke more than one year). They also found similar results as previous studies that a lower femoral bone minimal density (BMD) on their paretic side compared with their good side. Jørgensen, Crabtree, Reeve & Jacobsen (2000) showed before that there was modest correlation (r=0.6, p<0.001) between asymmetrical weight bearing and BMD changes in the lower femoral neck of the paretic side in stroke patients (seven months after stroke). These implied that the lower the magnitude of
the mean vertical GRF born on the paretic leg during walking, the poor the 
maintenance of the BMD in chronic stroke patients. These can also explained why 
incidence of hip fracture, especially the affected side, after a fall is common in 
stroke patients. Cheng, Wu, Liaw, Wong & Tang (2001) found that symmetrical 
body-weight distribution training in stroke patients resulted in more body weight 
distributed symmetrically in both legs and which consequently decreased number of 
falls in a group of sub-acute stroke patients (two to four months after stroke).

As Kim & Eng (2003) found temporal symmetry (both swing and stance 
symmetry indices) positively correlated (r=0.586 for stance symmetry index and 
r=0.678 for swing symmetry) with increased vertical GRF through the non-paretic 
limb in a group of chronic stroke survivors who able to ambulate without an walking 
aids, Patterson et al (2008) raised a new problem of prolonged increased force 
distribution over the non-paretic limb. They proposed that repetitive greater GRF 
loaded on the non-paretic limb may lead to some musculoskeletal consequence such 
as increased incidence of joint pain as a result of increased risk of degeneration. 
However, there was no study has examined this incidence in stroke population.

Apart from asymmetry gait pattern, slow gait speed was another important 
reported hemiplegic patients (post-stroke for 0.5 to 336 months) who were all 
functionally ambulatory with or without walking aids walked significantly slower 
than age-matched normal subjects (0.73 ± 0.38 versus 1.07 ± 0.17 m/s). Patterson et
al (2008) found that the mean gait speed of the chronic stroke survivors who able to ambulate independently with or without assistive device was $0.75 \pm 0.35$ m/s. Roth et al (1997) found in their 25 chronic stroke survivors who were ambulatory with or without an assistive device walked in a much slower speed with mean value of $0.43 \pm 0.31$ m/s. But they did not mention the number of subjects using the walking aids.

It is possible that walking aids may have profound impact on the gait speed.

Tyson (1998) found that the severity of the hemiplegia was significant negative correlated with the subject’s walking speed. It indicates the more severe the hemiplegia, the slower the subject can walk. In 1999, Tyson reported that there was a significant negative relationship between walking speed and the lateral sway ($r = -0.6$). Then there was significant positive relationship between the walking speed and the lateral symmetry ($r = 0.6$). That means the patients walked with faster self-selected speed presented with less lateral movement of the pelvis and more lateral symmetry in walking.

Chen et al (2003) also reported that walking speed decreased with poor motor control of the proximal part of the lower limb. They even concluded that proximal control rather than the distal control of the lower limb may be the main determinant of final walking speed of a stroke survivor. In support of their findings, Hsu, Tang & Jan in 2003 revealed that among the physical impairments, the strength of the paretic hip flexors and knee extensors were the most important determinants of the self-selected comfortable gait speed in mild to moderate severe stroke survivors ($R^2 = \)
Titianova & Tarkka in 1995 also found that the peroneal muscle groups’ strength was significantly lower in the lowest gait speed subgroup (speed smaller than or equal to 0.25 m/s) when compared to the highest gait speed subgroup (speed greater than or equal to 0.73 m/s). They also reported that no relationship between gait speed and asymmetry indices but hemiplegic patients with high swing asymmetry index associated with low self-selected walking speed (r = - 0.57 and p < 0.01). Moreover, Roth et al (1997) concluded that the walking speed of hemiplegic patients correlated with most of the parameters of gait. They found that swing symmetry and swing/stance ratio of the paretic limb were linearly correlated with walking speed but overall temporal symmetry was not related to gait speed. On the other hand, conflicting result was found by Brandstater, deBruin, Gowland & Clarke (1983). They found that overall temporal symmetry was related to gait speed in a group of persons with acute stroke. Patterson et al (2008) also reported that self-preferred walking speed was negative correlated with overall temporal symmetry (r = - 0.583). They also reported that subjects with a self-preferred speed less than 0.6m/s were more likely to exhibit a severe overall temporal asymmetry (2.1 ± 0.8). They found there was significantly difference in mean self-preferred speed between the severe asymmetry subjects and both the normative and mild symmetry groups but no difference between the mild and normative groups. It indicates that the more asymmetry the overall temporal value, the slower the gait speed.
After physical assessment of 147 stroke patients, Perry, Garrett, Gronley & Mulroy (1995) concluded that gait speed was determined to be the most efficient in predicting ambulation classification. They defined that a gait speed of less than 0.4m/s was equal to severe gait impairment and can be classified as household ambulation; a walking speed between 0.4 and 0.8 m/s indicated moderate gait impairment and can be classified as limited community ambulation; and finally a gait speed of greater than 0.8m/s indicated a mild gait impairment and can be classified as full community ambulation.

### 1.4 Using walking aids in gait training

Walking aids have long been used in peoples with ambulation difficulties such as elderly with poor balance, lower limb fractures, arthritis, stroke and other neurological disorder patients. Their main functions are to improve stability, avoid much weight bearing on some structures, alleviate pain and improve self-confidence in different persons according to their specific needs to facilitate independency in ambulation. Due to the characteristics of stroke, stick and quadripod are the most common walking aids frequently prescribed to stroke patients to improve their walking stability. However, there were limited studies to assess the efficacy of walking aids on balance or gait performance in stroke patients.

Milczarek, Kirby, Hirrison & MacLeod (1993) carried out a study to assess the effect of a cane (stick) and a four footed-cane (quadripod) on the standing balance of
fourteen mild to moderate severity stroke survivors (post stroke for 162 ± 171 days, range: 34 to 721 days). They assessed the postural sway when those subjects stood, in a randomly balanced order, without a stick, with a stick, and with a quadripod. They revealed that a stick significantly decreased the postural sway in both medio-lateral and antero-posterior direction and shifted the mean position of the center of pressure towards the stick side. But they found that the quadripod offered no advantage over a stick. It may be due to most of their subjects (ten out of twelve) were already routine stick walker before they recruited for that study and only two of them were quadripod walker. That means most of them had already got used to a habitual standing pattern no matter what kind of walking aids they used. But the fact is that walking aids can significantly decrease the postural sway in static standing. However, Tyson (1999) found that walking aids (stick and tripod) has no effect on lateral sway when compared with unaided walking.

Kuan et al (1999) found that a cane could assist the paretic limb to shift the center of body mass smoothly towards the good limb and to enhance push off during pre-swing phase then result in significantly improving the hemiplegic gait. Chen C., Chen H., Wong, Tang & Chen R., (2000) showed that a cane not only provide support to stroke patients but also provide a braking effort to restrain forward motion onto the good limb in walking. Maeda, Nakamura, Higuchi, Yuasa & Motohashi (2001) also found that cane can improved the static Romberg standing stability by significantly decreasing the gravity-center sway (58% in male and 53.9% in female)
when compared with unsupported standing in stroke patients.

Bateni and Brain (2005) reviewed around 100 studies and confirmed that a stick could improve balance and mobility in older adults. The effect of walking aids on the risk of fall in stroke patients is less clear. Soyuer and Öztürk (2007) found that the fall incidence in 100 chronic stroke survivors who can ambulate with or without a cane was 47%. Thirty-six of them had fallen only once and 11 of them were repeat fallers. For the repeat fallers, 54.5% of the fall occurred while walking. The authors also emphasized that 52.7% of the one-time fallers and 90% of the repeat fallers did not use a walking aid. Moreover, the percentage of using a walking aid in non-fallers was higher than fallers. They concluded that not using a walking aid increased fall in ambulatory chronic stroke survivors. Therefore, it is a common practice nowadays that the stroke patients are initially prescribed with quadripod and then progressed to stick or even walk unaided if stability and weight bearing on paretic legs improved.

However, one frequent approach in stroke rehabilitation claimed that the use of a walking aid for support in gait training is detrimental to the development of a normal gait pattern (Sackley & Lincoln 1996; cited in Laufer 2003. Davies 2000). It is because asymmetrical gait patterns (decrease single leg support time and weight bearing on the affected side) are already some commonest feature of walking in stroke survivors (Mauritz 2002; Lin, Yang, Cheng & Wang 2006). In fact, Bacik, Saulicz & Gnat (2006) found that unaided walking showed a more symmetrical
distribution of the vertical and frontal GRF when compared with walking with cane or elbow crutch. Proponents of this treatment approach emphasized that use of a walking aid encourages the patient to shift more weight from the paretic leg towards the unaffected leg or the walking aids then results in a more asymmetry gait pattern. They also believed that the quadripod which has a large base of support will result in a more asymmetry gait pattern when compared with a stick. Tyson and Ashburn (1994) found 40% of their subjects tended to walk worse (shorter, slower or less symmetrical steps) with a tripod than either stick or high stick.

There were only a few studies which have examined and compared the effects of different walking aids on gait symmetry in stroke patients. After measuring the amount of weight taken through the aids by fifteen chronic stroke patients, who could walk short distances outdoors independently with or without a walking aid, during walking, Tyson (1998) proved that similar percentage of body weight was supported by different aids (stick, high stick and tripod). She found that there was a significant relationship between severity of hemiplegia and the percentage of bodyweight taken through the walking aid \( r = -0.67 \), and between severity of hemiplegia and walking aid’s contact time on the ground. Therefore, she concluded that the amount of support taken from a walking aid and how long the walking aid was in contact with the ground are determined by factors associated with the severity of hemiplegia, rather than the features of the aid (the height of the aid and the size of the base of support).
Chen et al (2000) also found that the peak vertical forces applied on a cane by stroke patients, who walked in their self-selected comfortable speed, were less than 25% (7 to 25%) of their body weight. However, they did not measure the percentage of body weight supported by the paretic leg and non-paretic leg in their study. That means similar percentage of body weight supported by different aids in hemiplegic patient does not mean the gait symmetry was also similar.

Laufer (2003) examined and compared the effects of a stick and a quadripod on weight distribution in three different stance positions that challenge balance more and may more closely simulate gait: with the heels aligned with each other and in staggered stepping positions with either the affected lower leg placed forward or with the unaffected lower leg placed forward. He also found that the transfer of body weight towards the walking aids during stance did not increase the asymmetrical weight distribution between the lower extremities even in staggered foot positions, because the majority of weight was transferred to the walking aids from the unaffected extremity.

Recently, Laufer (2002) examined the weight distribution between the lower legs and the walking aids in stroke patients in standing position. He found that very small percentage of body weight was leaned on both walking aids and the percentage of body weight shift to the quadripod was significantly more than that of the stick. However, this shift of weight towards the walking aids did not affect the percentage of weight bearing on the paretic leg but rather on the unaffected leg.
Obviously, the above studies mainly measured the effect of walking aids in gait symmetry in static standing position that could not truly reflect the dynamic pattern of gait in walking. Moreover, apart from weight distribution patterns, they seldom involve other important factors such as temporal factors to assess the effects of walking aids in gait symmetry. To my knowledge, there was only one study found that patients using an ankle foot orthosis or cane had significantly higher swing asymmetry index (Titianova, Pitkänen, Pääkkönen, Sivenius & Tarkka; 2003).

Moreover, three studies recently have assessed the effect of walking aids on gait speed in stroke patients. Kuan et al (1999) reported that there was no significant difference in gait speed between walking with a cane and walking without a cane in 15 sub-acute to chronic (onset of stroke 2-42 weeks) stroke patients who could walk independently for 10 meters with walking aids for 2 weeks. They found that stroke patients walked at a significantly lower speed (0.29 ± 0.19 m/s) than matched normal elderly people (0.94m/s). On the other hand, Chen et al (2000) reported that the gait speed of chronic stroke patients walking with cane were relatively slower (0.42±3.58m/s). Anyway, both of them did not address the difference of gait speed when different walking aids were used.

Recently, in 2005, Buurke, Hermens, Erren-Wolters and Nene compared the walking speed of thirteen sub-acute to chronic stroke survivors in three different walking conditions: walk unaided, walk with stick and walk with a quadripod. All their subjects walked with a cane during normal everyday activities. They found
significant lower walking speed when walking with a quadripod was compared to a stick (0.39 versus 0.44 m/s) but they did not mentioned whether it is self-selected comfortable speed or not. Moreover, their sample size is too small.

In summary, the subjects involved in the previous analysis were mainly chronic stroke survivors and reliance on walking aids during normal daily walking. They may have already got used to their habitual standing, walking pattern and pace of walking, which may difficult to be affected by different walking aids. Obviously, there was still no clear consensus of the effects of walking aids on the symmetry of gait, gait speed and weight bearing patterns in stroke survivors.

1.5 Aim of the study

Therefore, the purpose of this study is to

1) Assess the effect of a stick and a quadripod on force distribution by measuring and comparing the mean GRF in mid-stance phase of each foot and the temporal asymmetry in a gait cycle in sub-acute stroke patients who are under going active rehabilitation program in a hospital setting.

2) Assess the effect of a stick and a quadripod on gait speed in the same group of patients.

1.6 Hypothesis
The null hypothesis is that there is no statistical difference in mean ground reaction force, temporal asymmetry values, and self-selected comfortable gait speed in walk unaided, walk with stick and walk with quadripod.

The alternative hypothesis is that there is statistically difference in mean ground reaction force, temporal asymmetry values, and self-selected comfortable gait speed in equal to or more than one of the comparison in walk unaided, walk with stick and walk with quadripod.