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# A COMPARISON OF THE RANGE OF WALKING SPEEDS BETWEEN NORMAL AND HEMIPLEGIC SUBJECTS

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**ABSTRACT. It is known that people who have suffered stroke walk slower than normal. However, their ability to deviate from a preferred speed of walking has not been reported. This study investigated the range of walking speeds of 20 hemiplegic subjects and compared the results with those of 20 normal age- and gender-matched controls. All subjects traversed a computerized grid walkway which measured selected temporal and spatial gait parameters. Subjects walked at five self-selected speeds: "normal"; "slower than normal"; "slowest"; "faster than normal"; and "fastest". Comparisons were made between velocity, range of velocity, stride time and stride length. The hemiplegic group walked significantly slower at all speeds, were less capable of adapting the speed of their gait, possessed a markedly reduced range of walking speed, and walked more cautiously than the controls. These deficiencies are likely to limit the stroke person's ability to respond to environmental demands.**

*Key words:* gait, hemiplegia, velocity.

Stroke continues to be an international health care problem. In North America it is the third leading cause of death and is the primary cause of disability in the elderly (16, 22). It has been estimated that in Canada each year, roughly 40,000 people will suffer a stroke. This compares with 575,000 new cases per year in the United States (12) and approximately 110,000 in the United Kingdom (10). In the United States, the American Heart Association (1) estimated that there were 3,020,000 stroke survivors alive in that country in 1992. It is known that the incidence of stroke increases with age, and, given that it is projected that the number of elderly in the developed world will continue to rise and that survival rates following stroke are increasing due to improved medical management, disability as a result of cerebrovascular disease will continue to exert a considerable demand on health care systems for some time to come (8, 19, 20, 21).

A primary therapeutic approach in the management of stroke is the rehabilitation of the survivor (5). This process places considerable emphasis on the re-education of disordered motor ability. Walking is often compromised and is a prime target of rehabilitation following stroke because of its importance to functional independence (29).

The diminished velocity of the hemiplegic gait, in comparison to normal, has been reported repeatedly along with associated limitations in stride time and stride length (4, 24, 31). Particular reasons for this deficiency have been proposed to be slowness in advancing the affected leg in swing and inadequate shifting of weight over the affected leg in support (31). Knutsson & Richards (18) subdivided a sample of stroke subjects on the basis of the electromyographic activation patterns in six muscle groups of the lower limbs. They found that, in terms of walking speed, patients with a Type II activation gait pattern (characterised by an abolition or a marked decrease in electromyographic activity in two or more of the recorded muscles in the hemiparetic limb resulting in poor knee flexion during swing, foot/floor discrepancies and hyperextension during the support phase) walked the slowest of the three groups at a velocity of 0.47 m/s (range 0.18–0.78). Subjects with a Type III pattern (marked by abnormal co-activation of several of the recorded muscles caused by high levels of spasticity and dominance of primitive synergistic motor activity) walked at a velocity of 0.62 m/s (range 0.59–0.71). Subjects with a Type I pattern (characterised by premature activation of the calf muscles which was combined with low levels of activity in the anterior tibial group while the other muscles in the affected lower limb demonstrated normal or near normal activation patterns) were the fastest walkers of the three groups ambulating at

0.72 m/s (range 0.53–1.03). However, for different reasons, all three groups walked slowly compared with normal.

It has been reported that hemiplegic subjects demonstrate spatiotemporal asymmetries and experience difficulties in single limb balance between limbs (11). Altered temporal parameters of gait have also been identified with increased time spent in double support phases and reduced time spent in single support (33). This finding is similar to that found in elderly fallers by Wall et al. (34) who proposed that this profile was associated with a "cautious" gait pattern probably resulting from compromised balance.

In a study conducted by Wall & Turnbull (32), the self-selected, preferred speed of the hemiplegic sample studied was extremely slow with a mean stature-relative velocity of 0.25 stat/s. Only 2 subjects out of 25 were able to reach velocities of 0.4 stat/s, a speed regarded as being in the slow range for normal elderly people (23). This velocity decrement has potentially important functional implications. For example, many environmental factors, such as signals at cross-walk intersections, are geared towards a much faster walking speed (17). Although it is known that hemiplegic subjects walk slowly, Giuliani (11) has drawn attention to the fact that very little research has been conducted on the speed related changes in the hemiplegic gait patterns. Little is known, therefore, of the velocity adaptability of hemiplegic gait. One study which did examine different walking speeds was that conducted by Bohannon (3) who found a significant difference in velocity between a group of hemiplegic subjects' "comfortable" walking speed and their maximum safe speed". This study, however, investigated no gait parameters other than velocity and examined only two walking speeds. Harro & Giuliani (15) found that the self-selected walking speeds of hemiplegic subjects were considerably slower than normal and reported deficiencies in the ability of hemiplegic subjects to increase walking speed compared to controls. This poverty of walking speed has traditionally been attributed to decreased joint movement amplitudes and step lengths as well as an inability to produce selective movement in the joints of the lower limb and poor balance (6, 25).

Attempts by hemiplegic subjects to walk faster may result in an accentuation of the gait abnormalities because of the apparent direct relationship between asymmetry and speed (4, 7). This could result from increases in levels of spasticity with an associated increase in gait asymmetry as a result of effort, a phenomenon that Bobath (2) has referred to as "associated reactions". Attempts to increase walking velocity may be a difficult proposition for stroke subjects because it has proposed that increases in movement velocity result in deterioration of motor performance (13). Attempts to increase walking speeds by hemiplegic subjects, therefore, may also result in problems of safety and a more abnormal gait pattern. This deterioration of performance, which remains to be systematically described in relation to hemiplegic gait, appears to be worthy of consideration as an important rehabilitation concern.

The purpose of this study was to investigate the range of walking speeds of which ambulant, hemiplegic subjects were capable and compare the resultant data with those of age- and sex-matched controls. In addition, the effect of velocity upon the parameters of stride time and stride length were examined.

## MATERIALS AND METHODS

A group of stabilised stroke patients ($n = 20$) was studied and compared with an age- and sex-matched control group. The study sample included 12 males and 8 females between the ages of 32 and 73 years (mean = 57.2 ± 10.65) who demonstrated residual hemiplegia from a single stroke suffered between 16 months and 20 years previously. This duration post stroke ensured that the neurological status of the subjects was stable. Twelve subjects demonstrated left sided hemiplegia and the remainder, right sided. Excluded from the study were patients with symptoms which were associated with a negative rehabilitation prognosis as described by Stonnington (28). These prognosticators included serious or unstable medical conditions, such as heart disease or uncontrolled hypertension, major perceptual disturbances including unilateral neglect, significant peripheral sensory loss, visual field defects including homonymous hemianopsia, marked cognitive disturbances including memory defects, severe intractable pain and incontinence of bowel or bladder. All subjects were capable of comfortably walking at least 50 m without the assistance of an ambulatory aid, such as a cane, however, all demonstrated, subjectively, an *"asymmetrical, hemiplegic gait pattern"*. Both right and left sided hemiplegics were included. Subjects with disabilities from other pathologies, such as osteoarthrosis of the hip, which would have potentially further interfered with the gait pattern, were also excluded as were those who suffered from receptive aphasia which would have compromised the giving of instructions during data collection. All stroke subjects had undertaken formal rehabilitation and had been discharged from this process.

The control group was comprised of twenty healthy individuals (12 men and 8 women), aged between 33 and 84 years (Mean = 61.5 ± 12.98) who were functionally and socially independent. Specific exclusion criteria were applied to ensure that no factors which were known to affect gait were present in the subjects of this sample. These criteria, proposed by Hogan et al. (17), consisted of a history of neurological disease, vestibular or inner ear disorders, severe visual disability, significant peripheral sensory loss, severe degenerative osteoarthritis, cognitive disturbance including memory loss, marked skeletal deformity, postural hypotension, chronic alcohol abuse, advanced cervical myelopathy, normal pressure hydrocephalus and multiple sensory disorder. These subjects were recruited from local, community-based groups located in the same metropolitan area from which the stroke subjects were recruited.

The temporal and distance kinematics of the gait cycle were measured using a computerized, resistive grid walkway originally developed by Wall et al. (30) and later modified by Crouse et al. (9). The walkway consisted of a series of mats into which a grid was set. The grid was made up of copper-clad steel welding rods embedded in ribbed rubber mats and which were situated 0.78 cm apart. Each mat had two grids so that the left and right feet were measured separately. The walkway was 10.4 m long with the central 7.2 m transduced. Dummy mats were placed at the beginning and at the end of this transduced area to eliminate the effects of the accelerations and decelerations at the commencement and conclusion of each walking trial. Thus, constant velocity gait trials were measured. Each subject had a strip of self-adhesive, aluminum tape attached to the sole of his/her own shoes which served to complete a current path to ground, when the tape was in contact with the mat, through the otherwise electrically isolated rods. The system provided data on spatial and temporal characteristics of the gait cycle and velocity, expressed in both absolute (m/s) and relative (st/s) terms. The unit of velocity referred to as relative speed was proposed by Grieve & Gear (14) to account for differences in walking speed as a result of subject height. To calculate this measure, velocity was divided by stature and was expressed as the number of times body height was covered in overground walking in 1 s. This measure has been shown to be better correlated to other gait parameters than velocity expressed in terms of m/s (26). Stride length was also measured in relative terms for the same reasons and reflected the percentage of stature covered in one stride.

All subjects were requested to walk at five speeds and received the same instructions prior to each walk in the following manner and sequence. The first trial was undertaken at the self-selected "free" speed of the subjects. Following this they were asked to walk "slower than normal" and then at "slowest" speed. An additional "normal" speed walk, during which data were not collected, was then interposed before the next tested walk. The purpose of this trial was to re-orientate the subject's perception of normal speed which was used as a reference point from which the subject determined variations in velocity. Subjects were then instructed to walk "faster than normal" and, finally, at their "fastest" speed.

## RESULTS

Data from the hemiplegic subjects were compared with those of normal age- and sex-matched controls utilizing two factors (subject type and walking speed condition), repeated measures ANOVA. Repeated measures on one factor (walking condition) were then conducted to identify differences between walking speed conditions for the hemiplegic group and the normal sample. *Post hoc* analyses utilizing the Scheffé test were then used to identify the location of the significant differences. Unmatched $t$ tests were used to test for differences between hemiplegic and normal performances at each of the walking conditions. The 0.05 level of probability was used throughout this study as the level of significance.

Table I shows the general characteristics of the subjects who took part in this study. Statistical testing showed no differences between the groups for age, stature and mass. The distribution of males and females was the same in both samples.

Fig. 1A compares velocity at each of the walking conditions between the hemiplegic and control samples.

Statistical analysis identified significant differences between type of subject (normal and hemiplegic) and the different walking conditions and demonstrated that a significant interaction existed between the two factors. Repeated measures on one factor for the normal group revealed significant differences between all walking conditions in the normal group. However, in the hemiplegic group, only one of the four adjacent speeds (between "free" and "fast") was significantly different. Comparison of the same walking conditions between the two groups showed clear

Table I: *Subject characteristics (**ns** = no significant difference).*

| | Hemiplegic | | | Normal | | | |
|---|---|---|---|---|---|---|---|
| Parameter | Mean | SD | (Range) | Mean | SD | (Range) | p |
| Number | 20 | | | 20 | | | |
| Age (yr.) | 57.2 | 10.7 | (30–77) | 61.5 | 13.0 | (33–84) | **ns** |
| Stature (cm) | 170.2 | 9.8 | (151–185) | 171.6 | 10.00 | (155–191) | **ns** |
| Mass (kg) | 77.6 | 15.7 | (52.7–114.5) | 77.7 | 15.1 | (46.4–101.8) | **ns** |
| Sex | 12 males | 8 females | | 12 males | 8 females | | |
| Years since stroke | 10.7 | 5.6 | (1.4–20.0) | Not applicable | | | |

differences with the normal group walking significantly faster at all conditions than the hemiplegic sample. Comparison of the "slowest" walking condition for the control group and the "fastest" condition in the hemiplegic group resulted in an insignificant p value (0.0544) indicating that the "fastest" walking speed of the hemiplegic group was not statistically different from the "slowest" walking speed of the normal sample.

Fig. 1B compares range-of-walking-speed data for each subject in both groups. The data have been sorted in descending range to facilitate comparison. Range of walking speed was calculated by subtracting the slowest walking speed for each subject from the fastest walking speed. The mean range-of-walking-speed for the hemiplegic sample was 0.30 stat/s ± 0.20 (range 0.07–0.68) while that for the control group was 0.66 stat/s ± 0.21 (range 0.44–1.13). Analysis showed that these differences were significant. Only six of the stroke subjects were within the range of the normal subjects while the remainder were below normal.

Fig. 1C shows the mean values and standard deviations for stride time obtained at each of the self-selected walking speeds for both groups of subjects. Analysis revealed significant differences between the two subject types and between the five walking speeds. However, unlike the findings for walking speed, no interaction between the two factors was detected indicating that stride time decreased in a similar manner in both groups with increasing walking speed.

In the normal sample significant differences in stride time for two of the four pairwise combinations were detected, the exceptions being for the stride times between the "free" and "fast" and the "fast" and "fastest" conditions.

When the stride time values for the hemiplegic sample were analyzed, significant differences were detected between three of the four pairwise combinations with no difference between the stride times at the "fast" and "fastest" conditions.

When the stride times for each of the walking

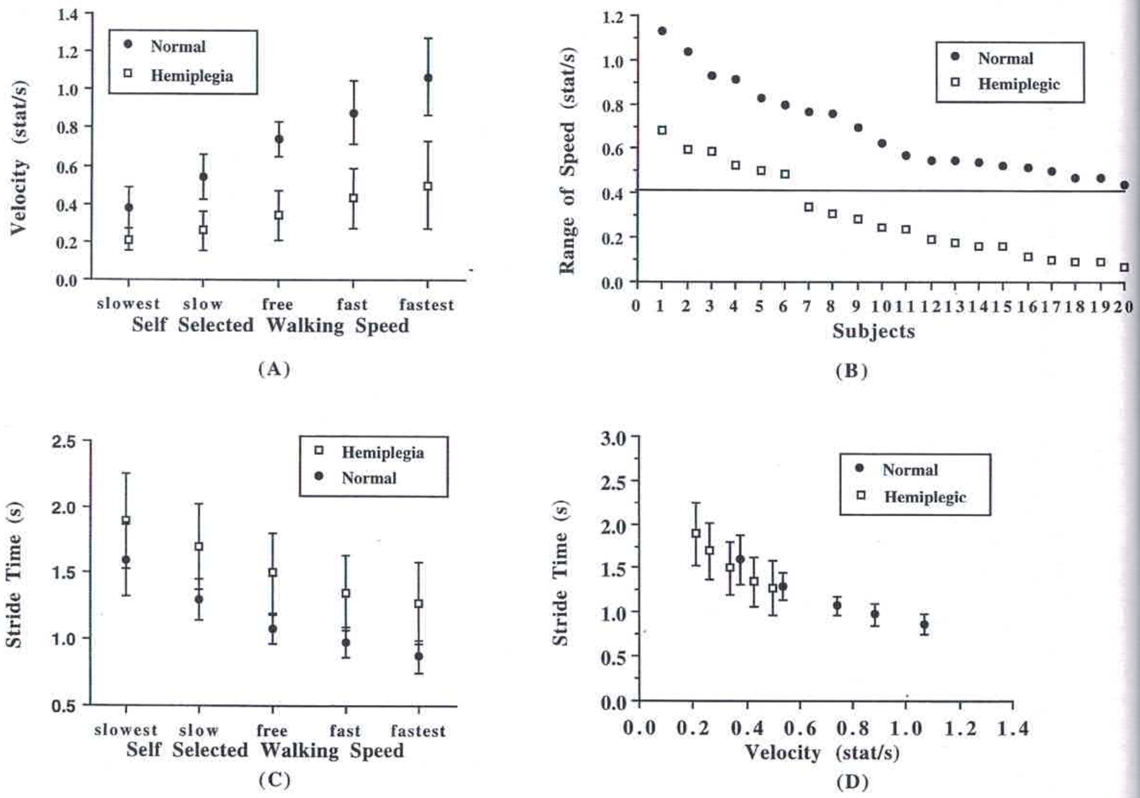

*Fig. 1.* Relative velocity at the five self-selected walking speeds (A), range of walking speeds for all subjects (B), stride times at the five self selected walking speeds (C) and stride time plotted against relative velocity (D).

speeds were compared between the groups, significant differences were detected between the groups for each of the same walking conditions. Further, the stride time for the hemiplegic group at the "fastest" walking trial was almost identical to the stride time for the control group for the "slow" trial.

These stride time values are plotted against relative velocity in Fig. 1D. The shape of the graphs for both hemiplegic and control groups are curvilinear and appear somewhat similar although the hemiplegic group demonstrated slower stride times overall. The absence of an interaction between type of subject and walking speed under the various gait testing conditions would tend to support the contention that the curves generated were similar.

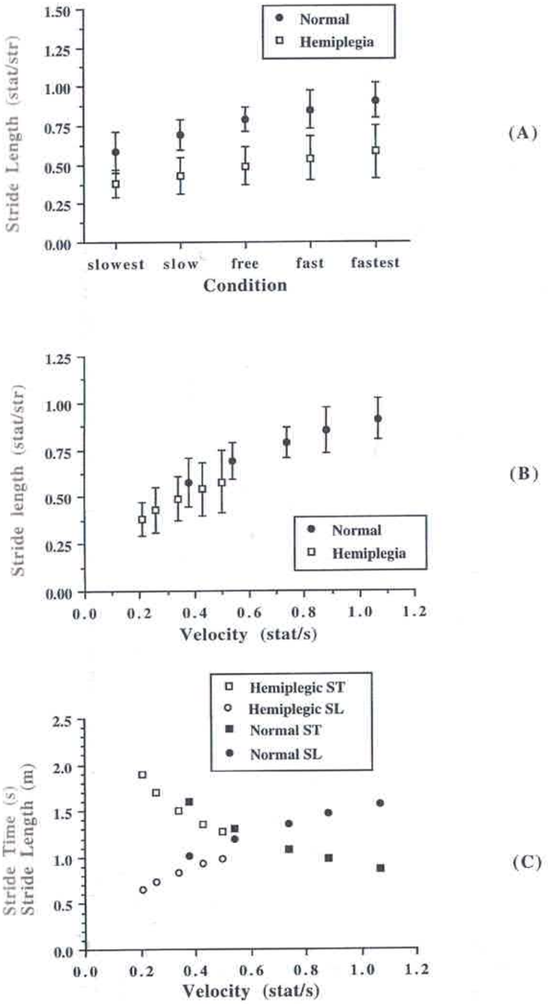

*Fig. 2.* Relative stride length at each self-selected walking speed (A), relative stride length plotted against relative velocity (B) and stride time and relative stride length plotted against velocity for both the hemiplegic and normal samples (C).

Fig. 2A compares stride length data (normalised for stature) of the two groups. Significant differences between the type of subject, the different walking conditions and a significant interaction between the two factors were demonstrated. In the normal group, *post hoc* analysis revealed that there were significant differences between all of the walking conditions except between the "fast" and the "fastest" trials. In the hemiplegic sample, no differences were found between the "slowest" and the "slow", the "free" and the "fast" and the "fast" and the "fastest" trials. Significant differences were found between all other pairwise combinations. Comparison between the two groups showed significant differences at each of the walking trials with the normal groups taking longer strides at all walking trials. The relative stride length for the hemiplegic group at the "fastest" condition was almost identical to that found for the control group at the "slowest" walking trial.

Fig. 2B shows relative stride length plotted against relative walking velocity for both groups. As expected, both groups demonstrated increasing stride length with increasing walking speed. However, like the measures discussed earlier, the hemiplegic stride length was less than that of the controls with only the stride lengths of the two faster speeds generated by the stroke subjects overlapping the stride length of the slowest speed of the normal group.

## DISCUSSION

In discussing the implications of this study, it must be borne in mind that the hemiplegic sample was a highly functional group. As such, these particular stroke subjects could be considered to be elite in terms of walking ability.

The control group increased walking speed in a manner to be expected given the nature of the instructions issued to the subjects. Significant differences were detected between all walking conditions. Thus, the normal subjects possessed the capability of consciously varying their walking speed between all conditions requested. Therefore, of the five speeds requested, the normal subjects were able to clearly demonstrate all five. This was not the case in the hemiplegic sample with no differences in walking speed being found between the "slowest" and "slow", between the "slow" and "free", and between "fast" and "fastest" walking test conditions. Therefore, only one of the adjacent walking condition pairs, that between the "free" and "fast" speeds, was significantly different. This would tend to suggest that when compared to the control group there was a limited ability in the hemiplegic group to consciously vary walking velocity, resulting in a fewer number of walking speed "gears" being available compared with normal.

The ranges of walking speeds were also found to be deficient in the hemiplegic sample. Although six of the hemiplegic subjects (perhaps those with the least amount of residual gait disability) possessed "normal" ranges-of-walking-speed, the majority did not. It is likely that, despite carefully controlling of the hemiplegic subjects who qualified for inclusion in this study, inter-subject variability within the hemiplegic sample may have led to the increasing variability found as walking speed increased. However, this finding should be considered in the context that this hemiplegic sample clearly walked slower than the normal group.

Although it was useful to examine self-selected walking speeds from slowest to fastest, such comparisons had limitations because the perceptions of "slow", "fast" etc. were specific to each subject. There was no way to control that a given perception of the velocity of gait was consistent between subjects. As such, the limitations of comparing psychometrically derived values were fully recognized. However, the procedure was designed to yield a range of walking speeds and increments between these extreme values. In this way, it was possible to examine temporal and spatial gait parameters, particularly stride time and stride length, at different speeds of walking. This was useful because it is known that gait velocity influences other gait parameters, both temporal and spatial (26). As a result of the generation of data at different gait velocities, it was possible to compare these other parameters both directly and as a function of gait velocity and to compare the performance of the hemiplegic subjects with that of age- and sex-matched controls.

It is known that there is a clear relationship between gait velocity, stride time and stride length. With increasing walking speed, stride time diminishes while stride length increases (26). Thus, many of the findings for stride time and stride length in this study could be accounted for by the simple fact that walking speed was increasing or decreasing. Fig. 2C plots both stride time in s and stride length in m against relative speed for both samples with a view to examining the interaction of stride time and stride length with walking speed.

It can be seen that the shapes of the curves for the hemiplegic sample were similar to those of the control group except that neither stride time nor stride length were of sufficient range given the range of walking speeds available. The normal values intersected at approximately 0.5 stat/s before diverging again, with increasing speed leading to shorter stride times and longer stride lengths. While the same was also true of the hemiplegic sample, the intersection did not occur and stride time and stride length remained restricted apparently by the limitations of the gait velocity to well below 0.6 stat/s. Thus, it appeared that the stroke subjects were unable to attain the stride times or the stride lengths of the normal subjects because they were unable to walk as fast. The converse of this statement may also have been true, that is, that the stroke subjects were unable to walk as fast as the controls because they were unable to take quick enough or long enough strides.

When the stride times and stride lengths were compared with those of the controls at the speeds which were common to both groups (the "free", "fast" and "fastest" for the hemiplegic group and the "slowest" and "slow" for the controls), the stride times and stride lengths for the hemiplegic sample were less than those of the controls. This finding indicates that the hemiplegic sample took relatively quick and short steps, suggesting an urgency to minimise single support and return to the more stable phases of the gait cycle when both feet were in contact with the ground. The quicker and shorter strides are suggestive of a "mincing" gait pattern, a term used by Wall et al. (34), to describe the cautious gait of elderly people with balance problems. This profile lends further support to the contention that the balance of the hemiplegic subjects is deficient.

From the perspective of rehabilitation, this study has important implications. The clear inability to alter walking speed and the significant reduction in the range of walking speeds found in the hemiplegic sample must have a functional impact. Attention to the rehabilitation of different walking speeds appears a worthy goal although it is a treatment objective which receives little mention in the literature. Given the results of this study, which showed that even an elite group of hemiplegic subjects walked substantially slower and with less velocity-adaptability than normal, attempts to rectify these deficiencies should be addressed. Examination of the two variables which influence walking velocity, namely stride time and length, may yield some clues as to how this objective may be reached. The interaction found between the independent variables (subject type and walking condition), which was detected for walking velocity, was also found for stride length but not for stride time. This would tend to suggest that some of the problem lies in the fact that the hemiplegic subjects were unable to alter stride length but were able to alter stride time in a manner similar to the control group. Therefore, during practice of gait in the rehabilitation setting, attempts should be made to increase stride length, probably by gradually progressing the length of each step as the patient gains more control. This could be done, perhaps, by providing subjects with a goal, such as a visual cue, which would encourage a longer step. In addition, patients should be trained to increase the speed of steps during treatment. Resultant improvements in the length and speed of each step would result in faster gait velocities. In proposing these strategies, it is recognised that for success to occur, it is likely that attention would have to be paid to the dynamic balance capabilities of the patient. A faster gait pattern demands greater displacement of the centre of mass of the subject which would briefly render the subject unstable (27). The ability to recover safely and smoothly from such a displacement is of paramount importance. Balance retraining, therefore, would be an important priority as a means of improving gait performance.

## CONCLUSION

The temporal and spatial gait kinematics, as measured in this study, were significantly different between the hemiplegic subjects and the age- and sex-matched controls. The hemiplegic subjects walked slower and possessed a greatly reduced range of walking speeds. Many of the differences detected in stride times and lengths could be explained by differences in walking speed between the two groups. However, when the gait patterns where the samples walked at similar velocities were examined, the hemiplegic group still took quicker and shorter strides. The implication of this finding is that the hemiplegic group walked in a cautious manner. The procedure of walking subjects at a variety of psychometrically derived rather than physically determined walking speeds, clearly demonstrated the extent of the gait velocity decrement in stroke. This finding would suggest that more attention should be paid to this competency during rehabilitation.

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