Locomotion Assistance Through Cane Impulse

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Summary

The extent of locomotion assistance gained through cane usage by those with hip disorders is assayed. Employing the propulsive impulse delivered by each leg of a healthy young male as a standard, the cane is shown to supply about one fifth the equivalent impulse. Full test values are given for nine handicapped subjects. The maximum value of propulsive impulse appears related to the time of floor contact with the cane.

Introduction

The cane acts to:

1. Increase geometric or static stability.
2. Supply sensory feedback of position and force.
3. Reduce the loading of internal body structures.
4. Contribute to gait braking and acceleration.

In this work, we shall review the initial three functions briefly and consider the last in some detail. This particular choice is not based on relative significance, of which we know little. We will concentrate on the propulsion aspect of cane use, simply because this area represents fresh ground.

Stability

Consider stability. Each time the cane is pressed against the ground, a tripod is constructed, consisting momentarily of two legs and the cane. The base area of the tripod is quite large compared with the base supplied by the two legs alone (Fig. 1.). So long as the action line or center of gravity of the ambulator is within the bounds of the base area, the ambulator is geometrically stable. The increase in stability is especially helpful to disabled persons on inclines, in high winds, or in cases of diminished ability to recover balance.

Sensory Feedback

Even small axial cane loadings may provide substantial sensory clues to a user. A cane may affect intact neuromuscular areas, bypassing some reflexes lost in certain types of handicaps. For example, a normal person's achilles tendon will be stretched slightly by forward sway of the body with respect

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to firmly planted feet. Those who lack voluntary control of forcible plantar flexion of the ankle, may receive adequate knowledge of body sway through upper limb deflections produced by guiding a cane.

Loading

The cane can be used to unload portions of the body, such as the hip joint (1,2). This is done by using the upper limb plus cane as a long lever arm. In this manner, even a modest push can produce a large moment at the body (Fig. 2). In the case of arthritic hip joints, the load relief derived in this fashion can make walking tolerable to many who would otherwise (without canes) be forced into wheelchairs.

Braking and Acceleration

Finally the cane can be used to provide some of the braking and accelerating forces ordinarily supplied by the legs, thus helping the basic process of propulsion. We shall consider the basic process of gait from the engineering mechanics point of view, starting with normal subjects (caneless) so that we may develop a frame of reference for cane performance. Then the characteristics of nine cane-using subjects, all suffering hip disabilities will be considered, relative to normal legged performance.

Our approach will be somewhat more than qualitative and somewhat less than fully quantitative, for the reason that certain of the data we present are sparse and some of the assumptions made to handle the limited data are necessarily quite gross.

Normal Gait

Consider the normal walker moving along at a steady pace. He possesses a certain momentum reflecting his weight and velocity. Thus:

$\text{Mom} = \frac{w\,v}{g}$ where the weight w and the acceleration of gravity g are combined with the mean forward velocity v. If we utilize the Drillis(3) value of 4.5 ft/sec forward velocity as representative of average normal young men, along with a 150 lb weight estimate, it can be shown (Fig. 3) that the corresponding momentum value is roughly 21 lb-sec. This value is the mean value in gait. Actually there are variations of momentum in each step cycle that are superimposed on the basic value. A full accounting of the momentum variation is made complex by the phased aspects of the two driving legs. For our purposes it is adequate to consider that variation in momentum owing to a single leg (Fig. 4). At the instant of heel contact, a braking process is initiated in which the basic forward momentum is considerably reduced. The braking process continues until the foot flat attitude is achieved. To this minimum value of forward momentum, the push-off process adds considerably, until at toe-off the entire initial momentum has been restored.

in other words the basic momentum level is continuously altered as a function of time. We may picture this process as a roughly sinusoidal variation in momentum about some mean value.

To compute the amplitude of the momentum wave, resulting from the action of a single leg, we shall use the classic impulse-momentum relationship:

Δ Mom = $\int$ Fdt where the change in momentum Δ Mom, is given by the integral of Force F and time t. In the case of normal subjects (Fig. 5) our data is taken from the University of California, Berkeley Locomotion Studies (4). The pertinent force for the forward momentum computation is the fore and aft shear force delivered to the ground, as measured by means of the force plate. The initial or negative area phase corresponds to the braking tendency following heel contact and the positive area portion corresponds to the momentum increase developed in push off.

If the subject is walking at a truly constant average speed, the negative and positive portions of the single leg impulse output must be precisely equal. Conversely any lack of equality implies that the subject is either slowing down or speeding up in the course of the gait. Analyzing three normal subjects by conventional graphical strip-integration procedures yields an average value of 4.3 lb-sec for the braking portion of the step and 4.8 lb-sec for the accelerating portion. Thus the Berkeley subjects are accelerating slightly despite the experimenters' efforts to produce a constant speed walk. As a practical measure we will consider a rough average value, 4.5 lb-sec, to represent the single leg impulse developed by normal young men in the course of the braking or accelerating phase of gait. The latter value is a useful base for comparing cane output. For this purpose we shall coin the term "Legsworth," equal to roughly 4.5 lb-sec of impulse and defined as that impulse, either braking or accelerating, delivered by either leg of a healthy young male while walking at constant velocity. Figure 6 summarizes the definition.

Cane Impulse Measurement Technique

An instrumented cane, arranged to measure axial thrust as a function of time, has been developed by Seireg (5) and used in combination with interrupted light photography at the Veterans Administration Hospital, Wood, Wisconsin, to survey cane force patterns of patients with a wide variety of disorders, including arthritis (6). The resulting data includes the angular attitude of the cane in both the anterior-posterior and medial-lateral planes. In other words, the cane load resultant plus that additional angular information necessary to determine directional components was obtained. A typical portion of raw-data is shown in Figure 7. By applying the fore and aft directional component to the cane load resultant, in a piece-wise fashion, strip integration of the force-time curve was performed. Thus if the cane angle from the vertical in a fore and aft sense is designated Θ, the process is one of computing $\int F \sin\theta dt$ where F is the cane resultant (thrust) load and t is the time of ground contact. Positive and negative values of θ indicate accelerating (positive) or braking (negative) phases of load transfer.

Subjects

Nine men were used in the study (Table 1) all of which presented with a diagnosis of unilateral hip arthritis secondary to degenerative joint disease and/or avascular necrosis. Subject number eleven exhibited degenerative joint disease twenty-one months post-fracture dislocation, subject fifteen exhibited degenerative joint disease secondary to trauma with no fracture, and subject number twenty-one had complaints of hip pain for eight years and eventually went to surgical osteotomy.

All subjects exhibited the limp associated with hip pain (coxalgia) as opposed to that which is seen as a result of muscle weakness, limitation of motion, or inequality in limb length (7,8).

Cane Test Results

Table 1 summarizes all cane test results in numerical fashion; Figure 8 presents a bar graph in which the braking and accelerating impulse of each subject is shown. These latter results are rank-ordered in terms of descending acceleration impulse, a base chosen largely for reasons of convenience. A single Legsworth of impulse is also shown, permitting a comparison between subject cane output and a Legsworth.

Results of some nine subjects are given. One of these, subject 1, appears twice. The second set of results was obtained in a replica test, superficially identifical to the first. Of interest is the amount of scatter reflected in the two "identical" tests. The largest impulse difference (0.21 lb-sec) between comparable test results is a likely indicator of probable scatter. It would be improper to assume that instrumental or calculational error alone accounts for this difference - it is more likely that small variations in gait play a key role in the generation of scatter.

As given in Table 1, the average subject develops 0.14 Legsworth of braking impulse and 0.31 Legsworth of accelerating impulse. Averaging these two values, one might say that cane output corresponds to roughly one fifth of a leg in terms of overall gait impetus. Braking impulse values ranged from 0.11 lb-sec to 2.28 lb-sec; accelerating impulse values ranged from 0.48 lb-sec to 3.86 lb-sec.

In order to develop large impulse values, the cane user may choose to employ either a large force or a long time of force application; available results (Fig. 9) suggest that an envelope exists describing the maximum impulse transfer as a function of cane contact time. The envelope slope, roughly 3 lb-sec/second of cane contact time, establishes that ceiling beyond which the cane user finds the application of additional momentum uncomfortable or unprofitable.

Discussion

Unlike the normal, each of whose legs must generate precisely equal values of acceleration and brake impulse in a constant velocity gait, the cane user has a perfectly free choice as regards the form (sign) and magnitude of cane imparted impulse. This freedom exists because the cane is redundant from the mechanics point of view; either leg is potentially capable of generating the appropriate counter to the cane, if required. Thus in principle the cane can be used to generate an accelerating impulse only or a braking impulse only, or any combination of such impulses and still maintain a constant velocity gait. In practice, the cane user trades-off many variables (pain, energy cost, stability, sensory feedback) to arrive at a combination he deems optimal. Without entering into the wisdom of each such solution, we consider the average result of nine such resolutions.

As given previously, the average cane user suffering severe hip pain, chooses to develop 0.14 Legsworth braking impulse and 0.31 Legsworth of accelerating impulse. Thus the "boosting" aspect of cane use is employed more extensively than the braking aspect, by roughly two to one. The average cane impulse developed is about one fifth Legsworth. Noting that the Legsworth unit is based on the leg action of healthy young men, whereas the subjects in this study are middle aged or elderly, it becomes apparent that the drawing of one fifth Legsworth from the arms of the subjects represents great muscular effort. Thus the use of canes for propulsion is seen as highly significant to the user; were it not so, he would not make the effort.

Still, is it not possible that propulsion benefits are fringe benefits and that the basic motivation of the cane user lies elsewhere? That is, perhaps in the course of relieving pain (or increasing stability, etc.) the canes are inadvertently used in a fashion helpful towards propulsion. Nothing in this work permits any response to this issue. It can only be said that those suffering hip pain do use canes in a manner calculated to aid propulsion and that the personal cost in terms of muscular effort is high.

Conclusions

Some nine cane users experiencing hip disorders, either of degenerative joint disease or aseptic necrosis, were tested to determine cane effects on propulsion. It was learned that:

1. The average cane braking impulse developed in gait was 0.61 lb-sec or 0.14 that equivalent value generated by a normal leg. Braking impulse values ranged from 0.11 lb-sec to 2.28 lb-sec.

2. The average cane acceleration impulse developed in gait was 1.41 lb-sec or 0.31 that equivalent value generated by a normal leg. Ac-

celerating impulse values ranged from 0.48 lb-sec to 3.86 lb-sec.

3. The cane represents about one-fifth of a healthy normal leg in terms of propulsive output.

4. The maximum rate of impulse transfer through a cane is roughly 3 lb-sec/second of contact time.

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Subject Physical Characteristics, Momentum, and Cane Impulse Results

SUBJECT	ETIOLOGY[a]	AGE	SIDE	HEIGHT (In)	WEIGHT (Lb)	AVE. VEL. (Ft/Sec)	AVE. MOMENTUM (Lb-Sec)	CANE BRAKE IMPULSE (Lb-Sec)	CANE ACCEL. IMPULSE (Lb-Sec)	CANE CONTACT TIME (Sec)
1	DJD	44	R	70.5	176	2.38	13.0	0.18	0.48	0.75
4	DJD	69	R	67	185	2.70	15.5	0.11	1.13	0.58
6	DJD	60	L	66	223	1.53	10.6	1.05	3.86	1.55
8	DJD	76	L	67	145	2.70	12.2	0.11	1.00	0.75
9	AN	43	L	74	172	3.39	18.1	2.28	1.43	0.69
11	DJD	31	L	70	150	2.17	10.1	0.18	0.88	0.90
15	DJD	67	L	66	170	1.47	7.8	0.46	1.76	1.50
20	DJD	46	L	65.5	136	2.04	8.6	0.79	1.30	0.85
21	(Pain 8 yrs.) Unknown	51	L	69.5	197	3.59	22.0	0.58	0.79	0.70
1	DJD	44	R	70.5	176	2.60	14.2	0.39	0.59	0.85
								0.61 AVE. ↓ 14% Legsworth	1.41 AVE. ↓ 31% Legsworth	

[a]DJD - Degenerative Joint Disease
AN - Aseptic Necrosis

Table 1.

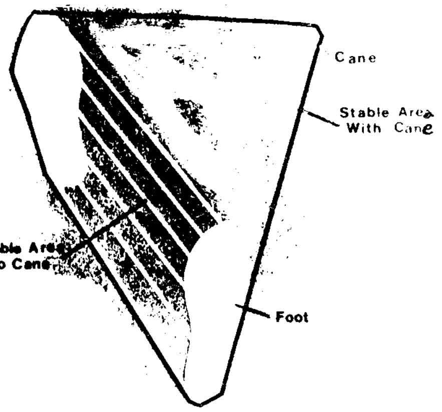

Fig 1-Cane & Static Stability

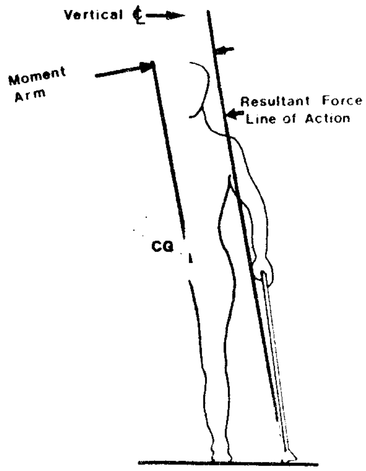

Fig 2-Cane & Internal Loading

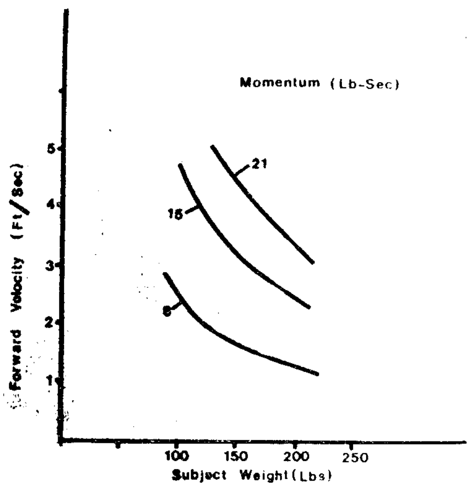

Fig 3-Test Subject Momentum

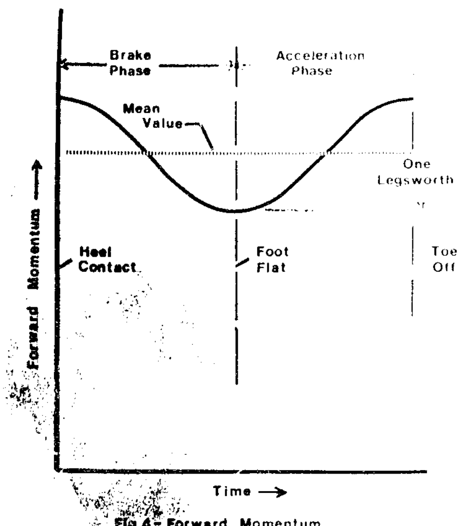

Fig 4- Forward Momentum. Normal Subject. Single Leg.

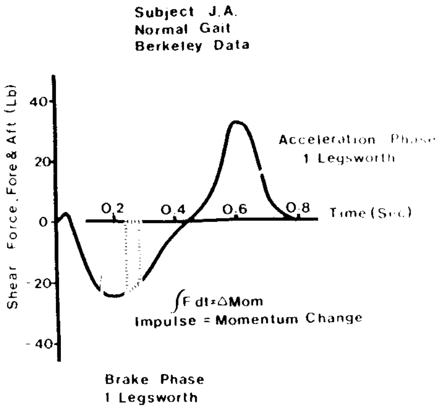

Fig 5-Impulse Computation
Normal Subject, Single

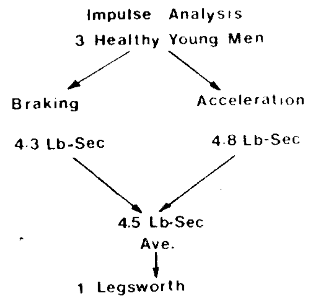

Fig 6-Definition of Legsworth

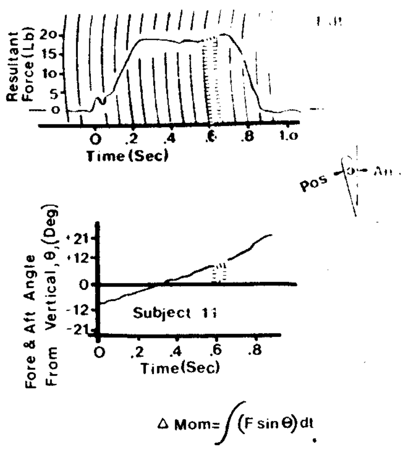

Fig 7-Cane Impulse Computation

Data From Murray

Wood Wisconsin VAH

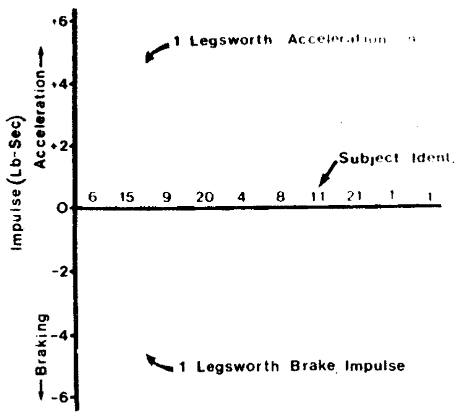

Fig 8-Cane Impulse Results

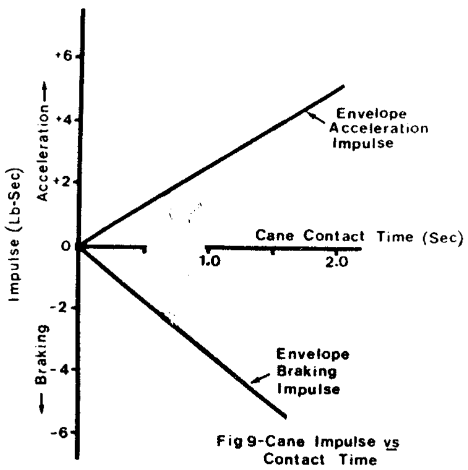

Fig 9-Cane Impulse vs Contact Time