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The efficiency and walking speed of visually impaired people

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The efficiency and walking speed of visually impaired people

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All pedestrians have a walking speed which they prefer. This appears to be the speed which, for them, is the most physically efficient. Blind pedestrians, if allowed to set the pace when accompanied by a sighted guide, will prefer to walk at a speed which is close to that of sighted pedestrians. However, when walking independently they adopt a pace which is slower than their preferred walking speed. By converting adopted walking speed into a proportion of preferred walking speed we are able to show that subject data may be pooled and comparisons made which had hitherto been impossible. Furthermore, statements may be made about the physiological efficiency of a performance. For example, efficiency varies with route difficulty, increases with increased preview, and only users of guide dogs reach their optimum efficiency.

1. Introduction

At least 30% of visually impaired people make no independent journeys outside their homes (Gray and Todd 1967, Clark-Carter *et al.* 1981). Aids are constantly being devised to improve the mobility of the visually impaired, and there is a need to evaluate the worth of such aids. However, to perform such an evaluation one needs criteria against which to make comparison. Leonard and Wycherley (1967) noted that there existed little understanding of what constituted good mobility and they proposed a number of sub-skills which should be achieved before a person's mobility could be considered adequate. This approach is not totally satisfactory, as achievement of many of the sub-skills is not a matter of degree, and thus it would not be possible to compare different levels of mobility; a person either can or cannot perform a sub-skill.

Armstrong (1975) identified three main aspects of mobility as needing evaluation: the safety of pedestrians, their efficiency and the degree of stress which they experience. By scoring specific events during passes of a given route and by having each person act as their own control, he devised an evaluation procedure which obviated the need for absolute criteria of mobility. Each person would walk the route twice: once using only the long cane and once using the long cane in conjunction with the aid which was being evaluated. This meant that an aid's worth could be assessed by its relative effect upon a pedestrian's mobility. Many of the events which Armstrong recorded were related to the use of a cane, such as cane contacts with shore lines, and this was an explicit recognition that most of the aids to be assessed in the foreseeable future will have to be used in conjuction with a cane as a primary aid; a cane remains the most effective means to detect holes in the ground. Examples of unsafe mobility include walking in the road and making body contact with obstacles. A measure of efficiency was the proportion of time on the route which was spent walking in the desired direction.

There are a number of shortcomings in Armstrong's procedure. Firstly, because the people used in such evaluations have to be capable of walking the test route using only a cane, they already have to have a high level of mobility. Consequently, their performance is close to a ceiling level on many of the measures, and thus even a good mobility aid may show little improvement (Dodds *et al.* 1983). Secondly, although the procedure is not specific to the secondary aid concerned, it *is* limited to use with pedestrians who use a cane. Thirdly, each person has to act as their own control, and thus if two aids are to be compared each subject would have to learn to use both aids. Fourthly, although Armstrong's technique deals with safety and efficiency, it does not include an equivalent measure of the stress which blind people are believed to experience. In this paper, we propose a new measure which deals with each of the above objections and which should prove a very useful additional evaluation tool—namely, Percentage of Preferred Walking Speed (PPWS).

1.1. *Walking Speed*

Cotes and Meade (1960) showed that energy expenditure increases with walking speed. If one takes into account the increased distance travelled at higher speeds and

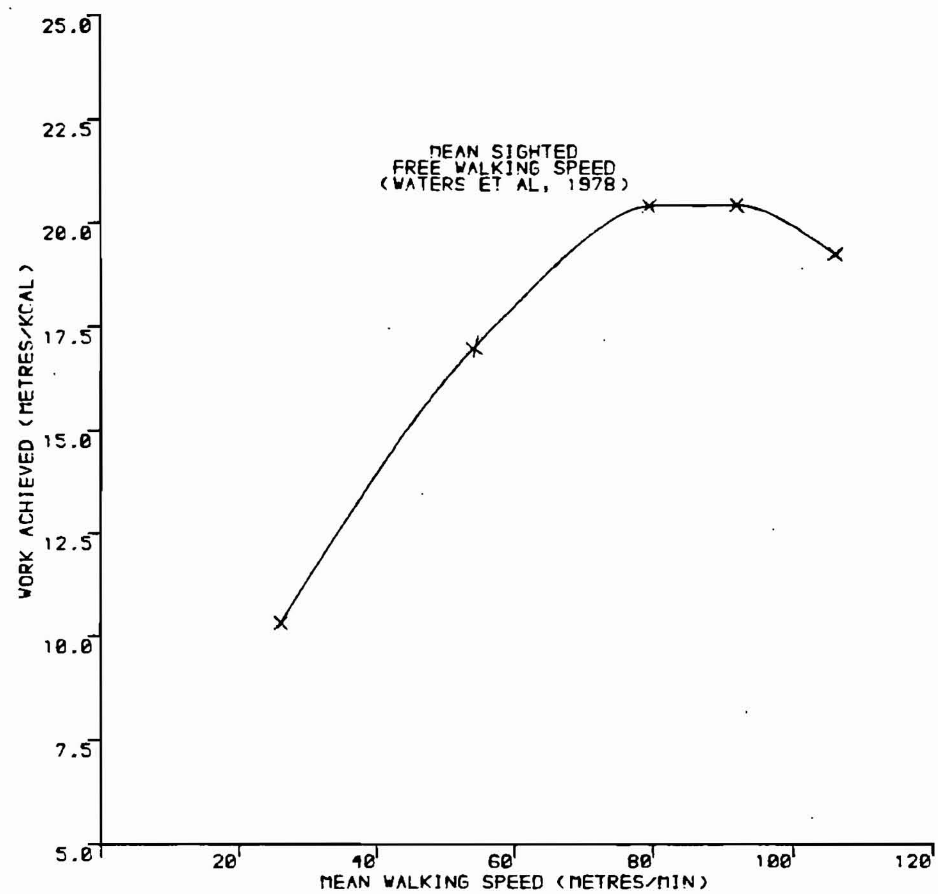

Figure 1. Work acheived by walking speed: sighted pedestrians. (Adapted from Cotes and Meade 1960).

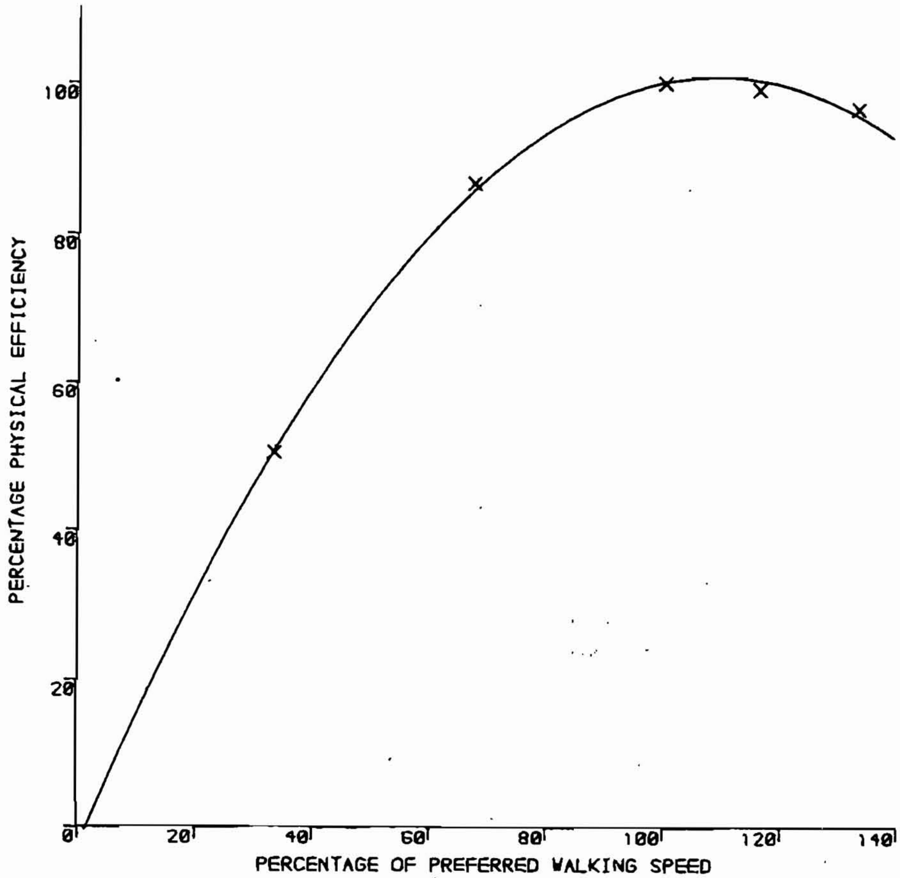

Figure 2. Efficiency by walking speed: sighted pedestrians (percentages).

replots their data it can be seen that there is an optimal, or most efficient, walking speed at which distance travelled per unit of energy expenditure is at a maximum (see figure 1). Waters *et al.* (1978) report their own and others' work which shows that on average people prefer to walk at a speed which is very close to that optimum.

Additional factors, such as age, leg length and body weight, affect the walking speed which people adopt and the relationship between walking speed and energy expenditure. However, Ralston (1958) found that individuals naturally walk at the speed which is the most efficient for them – their preferred speed. Figure 2 shows a graph of distance travelled for a given expenditure of energy (expressed as a percentage of the energy expended at the most efficient speed) against walking speed (expressed as a percentage of preferred walking speed).

A number of factors will affect the walking speed which a visually impaired person adopts. Among these are the complexity of the route and the type of mobility aid which is being used. It has been noted that at times when stress could be considered to be present blind pedestrians walk more slowly, and it has been hypothesized that walking speed might be an index of the degree of stress which visually impaired pedestrians experience (Heyes *et al.* 1976, Shingledecker 1978).

1.2. *The preferred walking speed of the blind*

It can reasonably be assumed that if the blind had their sight restored they would walk at more efficient speeds. This condition can be simulated if they take the arm of a sighted guide and they are asked to set the pace to that which they prefer. (A sample of six blind pedestrians walking under these conditions produced a mean walking speed of 96·5 metres/min. Reference to figure 1 shows that such a pace involves the minimum of energy expenditure.) The pace they adopt on subsequent independent passes of a route can then be expressed as a percentage of their preferred walking speed. This has three advantages over existing measures. Firstly, any ceiling in performance is the genuine ceiling of sighted mobility. Secondly, it is not reliant on a cane to provide scorable events, and can thus be used with aids, such as the guide dog, which are not used in conjunction with a cane, or with groups, such as the partially sighted, who may not need to use a mobility aid. Thirdly, different aids can be compared without the same subjects having to be trained to use each aid, as a score can be derived for each aid rather than for an individual subject. An experiment, which is to be reported more fully elsewhere (Clark-Carter *et al.*, to be submitted), investigated the effect of route complexity upon walking speed and also looked for evidence of psychological stress, using the Stress Arousal Check List (SACL, Mackay *et al.* 1978).

2. Experiment One

2.1. *Design*

The more complex a route the more the pedestrian is considered to be under stress. Accordingly, three routes were selected on the basis of their assumed difficulty. Route One – the simple route – was a straight stretch of pavement with a good, continuous inner shore line, and no obstacles at all. Route Two – the one of medium difficulty – was again a straight stretch of pavement, but the inner shore line was not continuous, the pavement was narrower and there were more obstacles on the outer shore line. Route Three – the complex one – was narrower still, had sections of ill-defined inner shore line, a greater density of obstacles – including some on the inner shore line, three turns and a road crossing.

2.2. *Subjects*

Two female and one male, late-blinded, long-cane users took part in the experiment. Their ages ranged between 25 and 45 years.

2.3. *Apparatus*

Each subject towed a wheel, which was attached to a harness (see figure 3), and wore foot-switches inside their shoes. As the wheel turned a light-beam was interrupted and this information was converted into audible tones which were recorded on a Sony TCS-310 Personal stereo for later computer analysis. The passage of the wheel measured the distance which the pedestrian travelled, the action of the foot-switches measured the occurrence of footsteps, and elapsed time was given by passage of the audio tape. The apparatus was worn throughout the experiment.

2.3. *Procedure*

The preferred walking speed of each subject was established in the way described above. Each subject then walked the routes independently, in the the order simple, medium then complex.

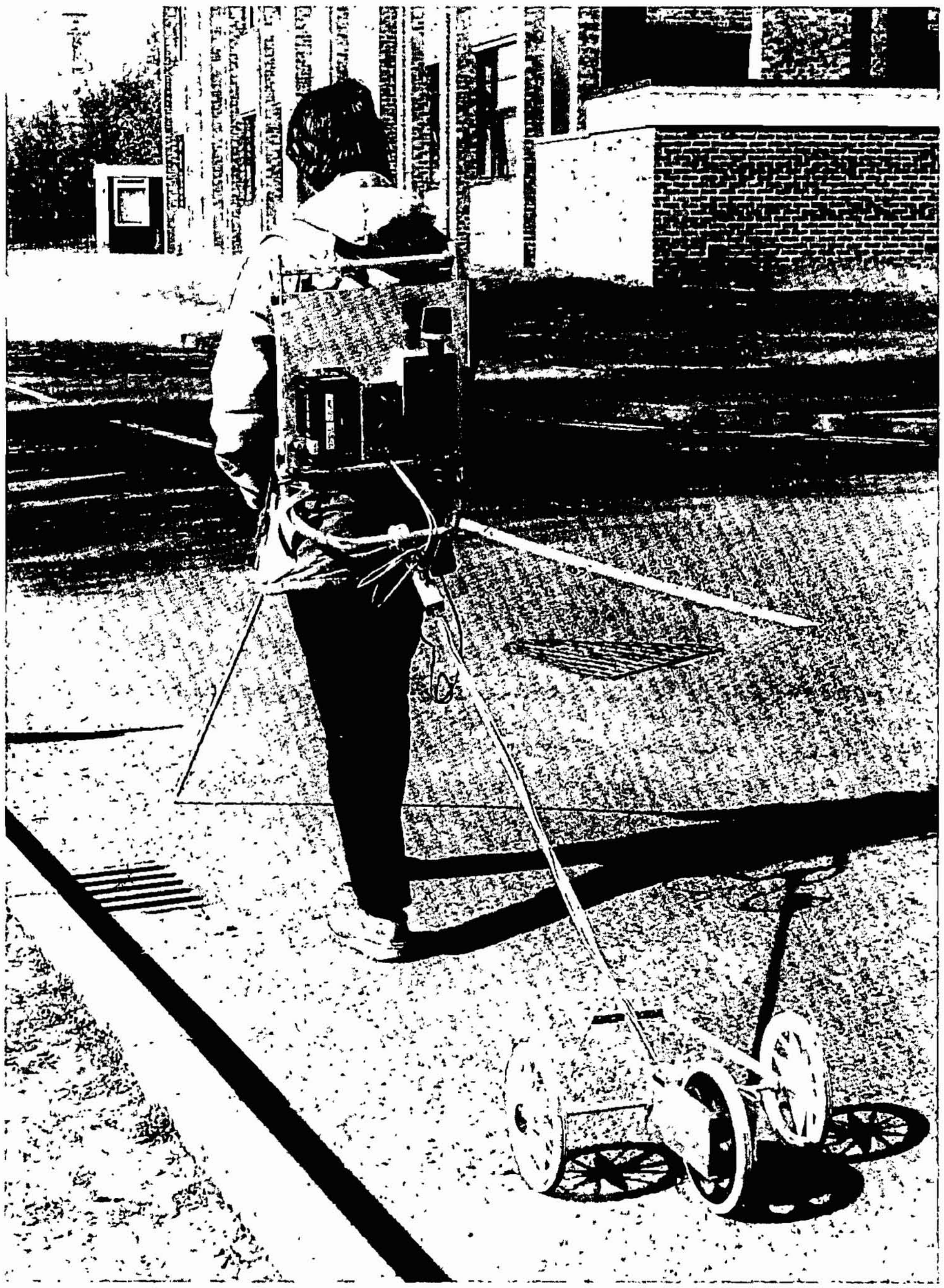

Figure 3. The apparatus used to measure walking speed.

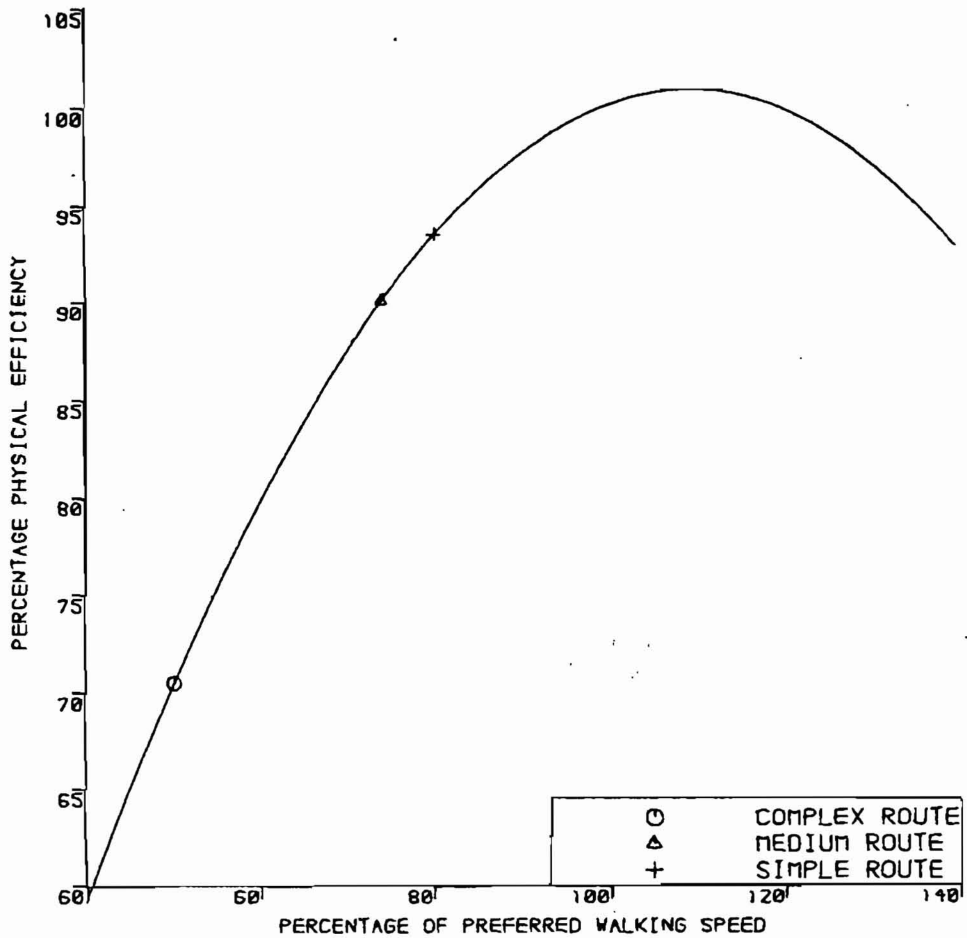

Figure 4. Physical efficiency by walking speed: route complexity.

2.4. *Results*

Subjects' walking speed was significantly lower when they walked the more complex route than when they walked either the simple route (planned comparison, $P = 0{\cdot}003$, one-tailed test) or the medium route (planned comparison, $P = 0{\cdot}005$, one tailed-test), and their speeds when unaccompanied were significantly slower than their preferred speeds (planned comparisons, complex route, $P > 0{\cdot}0005$; medium route, $P = 0{\cdot}0035$; simple route, $P = 0{\cdot}0103$; one-tailed tests). The effect of route difficulty upon walking speed is shown in figure 4 – the speeds being expressed as PPWS. The data are superimposed on the curve derived from Cotes and Meade (1960).

2.5. *Discussion*

Blind pedestrians do reduce their walking speed when they are independently mobile relative to their preferred pace, and the reduction is greater the greater the complexity of the route. However, the results of the SACL showed no evidence that this reduction is a consequence of psychological stress. The reduction is obviously partly a function of the degree of clutter on a route, for the more contacts a pedestrian makes, the slower will be the average speed. However, even during periods when they do not contact obstacles they adopt a pace which is slower the more complex the route. It is obviously prudent to walk more slowly when there is a greater likelihood of contacting obstacles or when one is unsure of the path ahead. However, although obvious, this does not detract from the usefulness of walking speed as a measure, for adopted walking speed is an indication of the pedestrian's confidence. In addition, below the optimal pace, the slower the walking speed the greater the physiological effort and thus the greater the physiological stress; this may account for much of the stressful nature of blind mobility.

3. Experiment Two

3.1. *The adopted walking speed of guide-dog users*

Many people who choose to have a guide dog give as their reason that it is the most effective aid at reducing the stress experienced during independent mobility. However, an alternative explanation is that the guide dog allows them to adopt a more physically efficient pace. A comparison was made of the walking speeds of guide-dog users and long-cane users.

3.2. *Subjects*

Two females and one male provided the data for guide-dog users. All were late blinded and had previously been users of the long-cane. The data for long-cane users comprised their preferred walking speeds and their performance, on the medium route, from Experiment One.

3.3. *Procedure*

A route of equivalent difficulty to the medium one used in Experiment One was chosen. Each person's preferred walking speed was established in the way described above. The guide-dog users then walked the route on two subsequent occasions: once with the guide-dog and once with the long-cane.

3.4. *Results*

Three analyses of the data were carried out. The first compared the absolute speeds of the guide-dog users across the three passes of the route. The second compared the absolute speeds of the guide-dog users and the long-cane users. The third compared the same groups but this time used as their data their PPWS. The first analysis showed that the guide-dog users were significantly faster when they walked with their guide-dog than when they used their long-canes (planned comparison, $P=0{\cdot}003$, one-tailed test), and their preferred walking speed was significantly faster than the speed which they adopted when they were using their long-canes (planned comparison, $P=0{\cdot}004$, one-tailed test). Both these results could be explained in terms of their long-cane skills having become poor due to lack of use. This possibility is also suggested by the second analysis which showed that the absolute speed of the long-cane users is *not* significantly slower than that of the guide-dog users (t-test, $P=0{\cdot}27$, one tailed test). However, the third analysis showed that when individual preferred walking speeds are taken into account and use is made of PPWS, the long-cane users *are* shown to walk significantly more slowly than the guide-dog users (t-test, $P=0{\cdot}006$, one-tailed test). Figure 5 shows the effect of the aid used upon PPWS. The data are superimposed upon the curve derived from Cotes and Meade (1960).

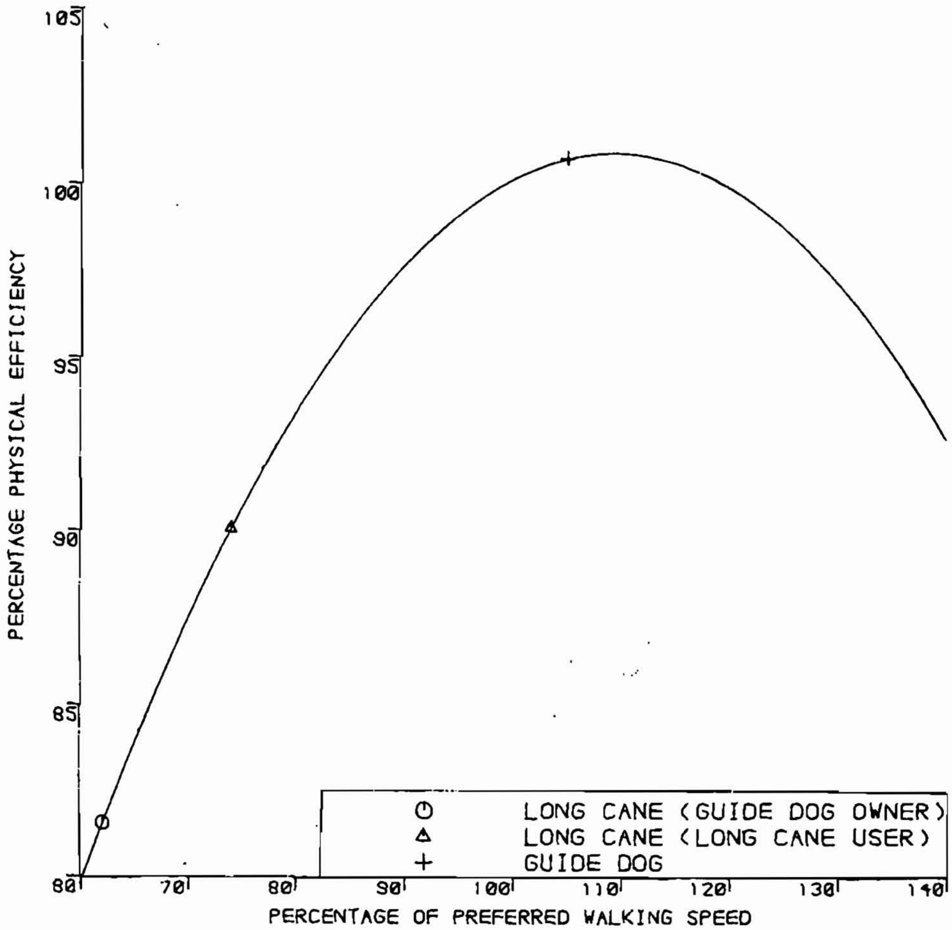

Figure 5. Physical efficiency by walking speed: guide-dogs versus long-cane.

4. Discussion

It can be seen that the use of the ratio between adopted and preferred walking speed (PPWS) controls for individual variations in preferred walking speed, and allows smaller samples to be used in experiments. This measure shows that the guide-dog enables blind pedestrians to walk at a pace which involves less energy expenditure than does the long-cane.

Long-cane users have to take responsibility for detecting and avoiding obstacles themselves, and because the cane gives them prior warning only about the presence of objects which are approximately one metre ahead, they will further reduce speed the greater the likelihood that obstacles are present. Thus, the more cluttered the route, the more slowly they walk. However, if they are provided with a secondary aid which gives them a greater preview of the path ahead, it is likely that they will feel confident enough to increase their pace.

In an experiment carried out before the value of PPWS was realized (Clark-Carter *et al.* 1986), a comparison was made of the walking speeds of six blind pedestrians when they were given different amounts of preview. Preview was presented using the Sonic Pathfinder, an ultra-sonic mobility aid for the blind which measures the distance

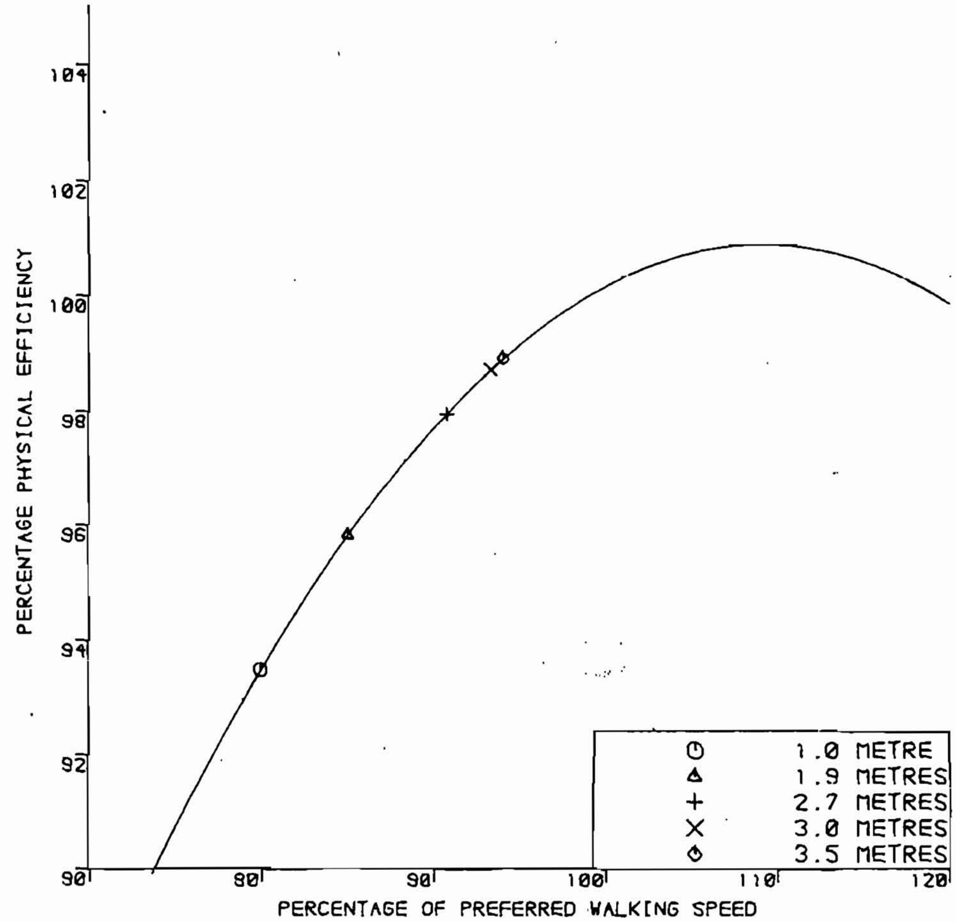

Figure 6. Physical efficiency by walking speed: preview.

of objects lying in the wearer's path and signals their distance auditorily (Heyes 1984). It is controlled by a programmable microprocessor and can carry up to 16 switchable options. This allows its range to be altered in the field. In this way, the effect of a number of ranges was systematically compared.

Subjects were able to walk significantly faster when they were provided with longer preview than they could with the long-cane (planned comparison, $P<0{\cdot}0005$, one-tailed test). Earlier experiments have shown that PPWS when the long-cane is used is approximately 75%. Although preferred walking speed was not measured in this experiment, it is possible to normalize the data with respect to the known PPWS for the long-cane on a comparable route. The results of providing additional preview are shown in figure 6; the data are once again superimposed upon the curve derived from Cotes and Meade (1960).

5. Conclusions

Preferred walking speed sets a goal towards which mobility aids should aim and against which they can be evaluated. Many advantages arise from expressing adopted walking speed as a percentage of preferred walking speed (PPWS). It need not be the only measure used: where appropriate, Armstrong's evaluation procedure should also be used. However, it emancipates evaluation of mobility aids from adhering to Armstrong's procedure when this is less appropriate. It is suggested that walking speed would not appear to be a measure of psychological stress, rather it is a function of confidence and of physiological stress.

Acknowledgments

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Tous les piétons ont une vitesse de marche préferée. Celle-ci semble être la vitesse qui leur paraît physiquement la plus efficace. Si l'on permet à un piéton aveugle de fixer son allure lorsqu'il est accompagné d'un guide voyant, il préférera marcher à une vitesse proche de celle de son accompagnateur. Cependant s'il se déplace tout seul, il adopte une allure plus lente que sa vitesse de marche préférée. En convertissant la vitesse adoptée en proportion de la vitesse préférée, nous avons pu montrer que les données individuelles peuvent être sommées; ce qui rend possible des comparaisons qu'il n'était pas possible de faire jusqu'à présent. En outre, on peut spécifier l'efficacité physiologique d'une performance. Par exemple, celle-ci dépend de la difficulté de parcours; elle augmente lorsque la pré-vue augmente et seuls les utilisateurs d'un chien-guide atteignent un rendement optimal.

Alle Fußgänger bevorzugen eine individuell unterschiedliche Gehgeschwindigkeit. Dies ist die Geschwindigkeit, bei welcher der höchste Wirkungsgrad erreicht wird. Wenn blinde Fußgänger in Begleitung einer sehenden Person das Schritt-Tempo angeben können, so wählen sie eine Geschwindigkeit, die sich nur geringfügig von der der sehenden Fußgänger unterscheidet. Jedoch wählen blinde Fußgänger, sofern sie ohne Begleitung gehen, eine geringere Schrittgeschwindigkeit als die bevorzugte. Setzt man diese angepaßte Geschwindigkeit mit der bevorzugten ins Verhältnis, so kann man zeigen, daß die subjektiven Daten normiert werden können und damit Vergleiche angestellt werden können, die bis heute nicht möglich waren. Darüber hinaus können Angaben bezüglich des physiologischen Wirkungsgrades der Fortbewegung gemacht werden. Zum Beispiel variiert der Wirkungsgrad bei unterschiedlich schwierigen Wegstrecken und steigt bei zunehmender Übersichtlichkeit der Strecke. Nur blinde Fußgänger, die einen Hund als Führer haben, erreichen einen optimalen Wirkungsgrad.

全ての歩行者は自分の好きな歩行速度を持っている。この速度は各個人にとって身体的に最も効率の良い速度と考えられる。盲目の歩行者は，付添いのいる場合には目の見える歩行者の歩行速度に近い速度で歩行することを好むが，付添い無しではこれより遅い歩行速度を採用する。盲目の歩行者が採用した歩行速度をその人が好む歩行速度に対する比に変換することで，被験者のデータを収集し，今までできなかった比較が行えるようになることを示す。さらに，歩行の生理学的効率について言及する。例えば，歩行路の難度による効率の変化，下見による効率の増加，そして盲導犬のみによる最適効率の達成などである。

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