The effect of a cognitive or motor task on the gait parameters of those with diabetes, with and without neuropathy

L. Paul [1], B M. Ellis[2], G P. Leese[3], A K. McFadyen[4], B McMurray[3]

[1] Nursing and Health Care – Faculty of Medicine, University of Glasgow, [2] School of Health and Social Care, Glasgow Caledonian University, [3]Department of Diabetes, Ninewells Hospital and Medical School, Dundee [4]School of Engineering and Computing, Glasgow Caledonian University

Contact Person

Dr Lorna Paul
Reader in Nursing and Health Care
Faculty of Medicine
University of Glasgow
59 Oakfield Avenue
GLASGOW G12 8LW
Email L.Paul@clinmed.gla.ac.uk
Phone 0141-330-6876
Fax 0141-330-3539

Running Title: Dual task interference during gait in diabetes

Abstract

Aims: To compare the gait parameters of older people with diabetes (DM) and people with diabetes and diabetic peripheral neuropathy (DPN) and to investigate the effect of a secondary motor or cognitive task on their gait.

Methods: Thirty subjects were recruited; 15 with DPN (mean age 69 ±3.0years) and 15 with diabetes and no neuropathy (70 ± 2.9years). The temporal and spatial parameters of gait were evaluated using the GAITRite walkway. Subjects undertook four walks under normal walking conditions (single task); four times while simultaneously undertaking an additional motor task, carrying a tray with cups of water (dual task); and four times whilst undertaking a cognitive dual task, counting backwards in sevens. This arithmetic task was also completed in sitting.

Results: For all gait variables there was a statistically significant difference between the groups. Subjects with DPN walked slower and with smaller steps compared to those with diabetes. In general the secondary task had a significant and adverse effect on the gait parameters and this effect was greater for those with DPN in both absolute and relative terms. Both groups had poorer arithmetic ability when walking compared to sitting.

Discussion: Patients with DPN have different gait parameters to diabetic patients without neuropathy. Problems with divided attention when walking were more evident in the DPN group and may increase their risk of falls.

Key words: Diabetes, Peripheral Neuropathy, Gait, Dual task interference, falls.

Introduction

Peripheral nerve damage affects approximately 25% of people who have had diabetes for 10 years, and 50% of those who have had the condition for 20 years (1). Diabetic peripheral neuropathy (DPN) affects the motor, sensory and autonomic nerves of the lower limbs and typically progresses in a symmetrical distal to proximal distribution (2-4). DPN can lead to a range of deficits including loss of vibration sense, tactile sensitivity, proprioception and muscle strength (2,5), which can result in alterations to balance and gait. It has been reported that a number of gait parameters eg. gait speed, step length, cadence, joint angles and ground reaction forces are different in subjects with diabetes and neuropathy (DPN) compared to control subjects or diabetic subjects without neuropathy (2,6).

Lower limb diabetic sensory neuropathy has an adverse effect on postural stability and walking (1) and ultimately increases the risk of falling in people with diabetes. Subjects with diabetic peripheral neuropathy are 23 times more likely to fall (7) and are 15 times more likely to report an injury compared to matched non-neuropathic subjects (1). Diabetes, and more specifically diabetic peripheral neuropathy, is a significant risk factor for falls (2,7).

Walking involves the activation of a large number of muscles in a co-ordinated and phase dependent manner (8). In many animals, most noticeably cats, locomotion has been reported to be primarily under the control of central pattern generators (CPGs) (8,9). These rhythmic generating, neural networks within the spinal cord are influenced by

afferent information and higher brain centres (9,10). Although less is known about CPGs in humans there is evidence that similar neural networks exist (8). As CPGs is that they are self sustaining spinal networks steady state walking may be considered a relatively automatic activity. The difference between CPGs in humans compared to other animals is the increased influence of cortico-spinal pathways in humans (10). However walking is not often steady state and higher brain centres are required when e.g. changing the direction of walking or moving around an obstacle (10). Thus walking requires the use of a proportion of the information processing capacity of the central nervous system, sometimes known as attentional capacity.

Dual task paradigms are used to study the degree of automaticity of movement. In these paradigms a primary task is undertaken, often walking, which is the main focus of attention. Secondary tasks are added and the resultant effect on both tasks is examined (11,12). In day to day situations it is normal for more than one task to be undertaken concurrently e.g. walking and talking thus these situations are in effect dual task paradigms. If the two (or more) tasks undertaken together exceed the available attentional capacity then there will be insufficient capacity to perform both tasks optimally and the performance of either or both tasks will deteriorate (13).

Dual task paradigms have not been studied to any extent in those with diabetes. One of the few studies examined the gait parameters of those with DPN during free walking and also walking whilst verbally responding to an auditory signal (14). Those with DPN were able to maintain a safe gait but were less able to respond accurately to the auditory

stimuli. Undertaking a different or more complex task may adversely affect the gait parameters of those with DPN however the effect of an additional cognitive or motor task on the gait parameters of those with diabetes has not been investigated.

Falls in older people with balance problems generally occur when the individual is walking and carrying out an additional activity such as talking (13) or undertaking a visuo-spatial task (15). People with DPN have reduced somato-sensory peripheral feedback and, to compensate for these peripheral deficits, those with DPN might make greater use of attentional capacity to help facilitate a safe gait pattern and prevent falls (14).

The aims of the study were to compare the gait parameters between a group of older people with diabetes and DPN, and a group of older people with diabetes but no DPN and to investigate if the addition of a secondary task, either cognitive or motor, altered the gait parameters in either of the groups.

Patients and Methods

Two groups of subjects were recruited; 15 subjects with diabetes mellitus with peripheral neuropathy (DPN) and 15 subjects with DM and no peripheral neuropathy (DM) (Table 1)**.** Subjects were recruited from the Diabetes Centre, Ninewells Hospital, Dundee. Participants were given written information on the study and written and informed consent was obtained. All procedures were approved by the Ethics Committee of NHS Tayside.

Table 1 Near Here

To be included in the study subjects had to be aged between 65 years and 75 years and have visual acuity of more than 6/18 on the Snellen visual acuity chart. Subjects were excluded from the study if they had cognitive deficits as assessed by a score of 23 or below on the Mini Mental State Examination (16), active lower limb ulceration or any co-morbidities known to affect gait parameters eg significant neuromuscular, cardiovascular or orthopaedic conditions, or were regularly taking medications known to affect the postural control system eg. Benzodiazepines. Subjects were also excluded if they required the use of a walking aid as it was not possible to complete the study protocol with a walking aid.

The DM and DPN groups had a confirmed diagnosis of diabetes mellitus based on the WHO criteria (17) and had had diabetes for a minimum of three years. For the DPN group peripheral neuropathy was confirmed by the presence of two of the following:

vibration perception threshold of >25 volts derived from a mean of three values, measured at the medial and lateral malleoli, and the first and fifth metatarso-phalangeal joints on both feet using a neurothesiometer (Horwell Scientific Laboratory Supplies, Nottingham, U.K.) (i.e. 24 measurements per subject); inability to detect a 10g Semmes Weinstein monofilament measured at more than two of the following sites, the first and fifth metatarsal heads, the pulp of the hallux and the heel on both feet; and a loss of lower limb proprioceptive sense assessed using a standard clinical limb matching test on both right and left sides (7).

A data sheet was completed for each subject which included information on the subjects relevant past medical history, duration of diabetes, results of retinal screening and results of neuropathic testing. Age, gender, height, weight and drug history was also recorded.

The primary task in the dual task paradigm being examined was walking therefore the main outcome measures of this study were the temporal and spatial parameters of gait, evaluated using the GAITRite walkway system. The GAITRite Gold (CIR systems, Inc., USA) is 61cm wide and 366cm long and contains 16,128 pressure-sensitive sensors. The GAITRite system was used to measure step length and duration; duration of single and double support; velocity and cadence. The primary outcome measure for this study was the gait velocity. Taped marks were made on the floor 1.5m beyond the each end of the walkway to allow an additional length for acceleration and deceleration (thus each ‘walk’ was over 6.5m). Subjects walked 12 times in total (see below) and the order of testing was randomised. The testing conditions were 1) subjects were asked to complete four

walks under normal free walking conditions (single task). 2) subjects walked four times while simultaneously undertaking a motor task which involved carrying a tray and four cups containing measured amounts of water (dual task). The position of the cups on the tray was marked for repeatability and note was made of any water spilled during the walk. 3) subjects walked four times while simultaneously undertaking a cognitive task which involved the subject counting backwards in sevens from a given number (dual task) and the number of correct calculations was recorded.

Subjects were also asked to undertake the cognitive task while seated. This was to establish each subject's arithmetic ability under single task conditions.

Statistical analysis

Each gait parameter was compared across the three experimental conditions and between the two groups using a two factor repeated measures ANOVA. Any interaction effects between the three experimental conditions and the two groups were also assessed. Suitable diagnostic checking of the assumptions of Normality and homogeneity of the variances were performed. Tukey's post hoc testing was performed when appropriate. This method of analysis was then repeated on the percentage change from 'normal walking' data in order to assess the relative change in each parameter. For this analysis the comparisons were between the two experimental conditions and between the two groups. Paired t-tests were used to make comparisons between the sitting and walking arithmetic scores. Analyses were performed on SPSS v15 and the level of significance was set at the 5% level.

Results

Forty six patients were invited to participate in the trial, and 30 (15 in each group) were included. It proved difficult to recruit women into the DPN group due to non-specific refusal (n=5), recent fall (n=2) and use of walking stick (n=5). At screening a further 4 subjects with DPN were excluded due to poor eyesight (n=2) and active foot ulcers (n=2). The mean age, gender, duration of diabetes, HbA1c results and VPT results are shown in Table 1. Subjects were asked how many falls they had sustained over the last year with a fall being defined as the individual unintentionally coming to rest on the ground, floor or lower level (Table 1).

Subjective responses by each group to the 10g monofilaments were: DM group100 out of a possible 120 detections and the DPN group 5 out of 120 detections. All patients in the DM group were able to consistently and accurately complete the limb matching tests for proprioception. For the DPN group however three subjects could not identify position sense at the right ankle, two at the left ankle and nine at both right and left great toes. These tests confirmed that the DPN group were presenting with severe neuropathy. One patient was on a tricyclic antidepressant in low dose for neuropathic pain.

In the DM group, 7 of the 15 subjects had no retinopathy, 8 had non-proliferative changes and none had proliferative changes. For the DPN group 5 had no retinopathy, 8 had non-proliferative changes and 2 subjects had proliferative changes. There was no significant difference ($p= 0.58$) in visual acuity between these two groups (mean VA was 6/6.8 for the diabetic group against 6/7.2 for the DPN group).

In terms of the effect of the additional task on gait parameters the results for step length and time on the right and left sides were very similar hence results are only given for the right side (Table 2).

Table 2 Near Here

For all of the gait variables there was a statistically significant difference between the two groups (Table 3) and also between the three testing conditions (normal walking, walking whist carrying out a motor task and walking whilst performing an arithmetic task) thus only the results of post hoc analyses of the gait parameters are included.

The addition of the arithmetic task had a significant and detrimental effect on all the gait parameters recorded (Table 3). The same was true when the secondary motor task was undertaken, except that step time was not affected to a statistically significant level ($p=0.145$). Both secondary tasks had similar effects on velocity, step time and cadence however step length and time of double support were more affected by the motor task than the arithmetic task (Table 3).

Thus overall there was a statistically significant difference in the gait parameters between the DM and DPN groups. The addition of both cognitive and motor tasks adversely affected the gait parameters, with the exception of the effect of the motor task on step time.

This analysis was performed on the absolute values of each of the gait parameters however during normal walking the gait parameters of the DPN group were different to that of the DM group and thus a comparison was made between the relative change in each of the gait parameters with the secondary task i.e. The percentage change of each parameter with respect to the gait parameters during normal walking.

The relative change in each of the gait parameters with both the cognitive and motor task was greater in the DPN group compared to the DM group (Table 4). Whilst these were not statistically significant differences many of these changes may have functional and clinically implications. For example in the DPN group the walking velocity reduced by an average of 35.2% from an already compromised normal walking speed of $98.6cm^{-1}$.

The effect of the secondary task on the primary task of walking has been discussed however the reverse relationship is also important. In terms of the effect of gait on the secondary (cognitive) task the DM group had 1.95 correct arithmetic calculations when walking and 2.77 when seated ($p=0.004$) and the DPN group had 2.15 correct answers walking compared to 2.78 when seated ($p=0.023$). Thus both groups were unable to maintain the same level of cognitive function when walking.

With respect to the secondary (motor) task the DM subjects spilled water on 35 of the 60 ‘walks’ and the DPN group spilled water on 52 of the 60 walks. This result was statistically significant ($P=0.006$).

In summary patients with diabetes and peripheral neuropathy (DPN) presented with a different gait parameters compared to diabetic subjects without neuropathy (DM). With one exception, the addition of either a motor or cognitive task adversely affected gait for both groups although the effect was more pronounced in the DPN group in relative terms. Additionally, both groups had significantly fewer correct arithmetic answers when walking compared to sitting and the DPN group spilled more water during the motor task compared to the DM group.

Discussion

The average walking velocity of the DPN group of 0.98ms^{-1} was similar to that reported in other studies investigating gait parameters in people with peripheral neuropathy, including DPN, where walking velocities have ranged from 0.85ms^{-1} (18) to 1.06ms^{-1} (14). Cadence was lower in our study (100 steps per minute) compared to other studies at 102 to 106 steps/min (14, 19), and step length was greater at 0.58m rather than 0.48 to 0.49m (20,7). The small discrepancies in the figures can be explained in the many ways used to analyse the temporal and spatial parameters of gait. What is quite consistent however is the overall pattern of a relatively slow velocity, shorter steps and lower cadence in people with diabetic peripheral neuropathy. This conservative gait pattern, which occurs as the individual attempts to maintain stability when walking, is also evidenced by the relatively high double support time. The explanation for the gait pattern may be related to the lack of sensory information from the lower limbs associated with peripheral neuropathy (2) or to reduced muscle strength of the ankle plantarflexors (19) or dorsiflexors (21). As peripheral neuropathy disturbs both efferent and afferent pathways (1) some combination of both explanations is possible. When ice was used to reduce the cutaneous sensation from the foot in healthy subjects a “cautious” gait especially in ground contact and the push off phase of gait was recorded (22).

A secondary task, motor or cognitive (arithmetic), adversely affected the gait parameters in each of the groups (with the exception of the effect of the motor task on step time). The effect was more marked, however, in the DPN group in both absolute and relative

terms. So not only did the DPN group have a significantly altered gait pattern during normal walking but the relative effect of the secondary task was greater in this group.

In terms of the effect of gait on the 'secondary task', both the DM and DPN subjects had poorer arithmetic ability whilst walking than seated and, in addition, the motor task was performed less adequately in the DPN group, as evidenced by more water spillage, compared to the DM group.

This suggests that patients with diabetes (both DM and DPN) probably used a greater proportion of their attentional capacity to maintain their gait pattern but to the detriment of the both the cognitive task and motor task. As the gait of those with DPN was more affected by the secondary tasks it appears that subjects with DPN were less able to divide and divert their attention which lead to a deterioration in their gait and also both secondary tasks.

Most previous studies on dual task interference have involved subjects with central neurological disorders such as Parkinsons Disease (23) or stroke (24) thus few studies have examined the paradigm in people with peripheral neurological impairment. Whether mediated through CPGs, reflex activity or higher cortical centres the control of human walking requires sufficient and appropriate afferent information to produce a co-ordinated motor response. One possible explanation for the results observed in this study is that the lack of sensory information from the periphery in DPN results in people using their attentional capacity to maintain their gait, and thus leaving less reserve capacity for

other simultaneous cognitive tasks eg arithmetic (14). In other circumstances people are able to compensate for a lack of input from one part of the somatosensory system by relying on information from other parts of the system eg. The visual system. However patients with diabetes may also have impaired sight e.g. from diabetic retinopathy or cataracts (13) preventing such compensation occurring.

Only one previous study was identified which examined the effect of dual task interference on gait in people with DPN (14). This study reported that reaction times (ie the results of the secondary task) were greater when subjects were walking (ie primary task) compared to sitting. This finding was similar to that of the present study where the results of the arithmetic task were better when seated compared to walking. The previous study did not, however report, the gait changes when the secondary task was added.

An altered gait pattern, problems with dividing attention when walking, and insufficient compensatory capacity within the somatosensory system may increase the risk of falling for those with DPN. The incidence of falls in those with diabetes is higher than an age matched population (25). The risk of falls may be further exacerbated by uneven surfaces, poor lighting, use of walking aids, drugs e.g. benzodiazepines, which were all excluded from the current study. This study, however, was not sufficiently powered to specifically investigate the relationship between dual task interference and the risk of falls in people with DPN. Further studies of people with DPN using dual task paradigms in more challenging situations is required. It is important that health care professionals recognise the potential for falls, specifically in those with DPN and implement

preventative strategies such as early advice and education. This may be simple instruction such as avoiding, or taking extra care when walking and carrying out another activity such as talking. For those with DPN and other known risk factors for falls such as co-morbidity, benzodiazepine use, education and referral to a specialised falls service should be offered if required.

In conclusion patients with DPN have a more conservative gait pattern, which is partly maintained by cognitive attention. For both the DM and DPN groups gait was readily worsened when distracted by performing secondary tasks. This effect was more evident in people with diabetes and peripheral neuropathy possibly putting such patients at particular risk of falls. It is important that health care professionals recognise the potential for falls in those with DPN and implement early preventative strategies (25,26).

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Declaration of Competing Interests – None to declare

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Table 1 – Description of subjects

Group	N	Mean age ±SD (years)	M:F	Number of fallers	Hb1Ac(±SD) and range	Duration of diabetes ±SD(years)	VPT ±SD (v)
DM group	15	70 (± 2.9)	7:8	4	7.7% (±0.79) 6.6-10.0%	14 (± 4.9)	16.6v (±5.4)
DPN group	15	69 (± 3.0)	11:4	4	8.0% (±1.7) 5.6-11.5%	15 (± 13.3)	36.3v (±8.3)

M= Males, F= female, DM group = subjects with diabetes but no peripheral neuropathy and DPN group = subjects with diabetes and peripheral neuropathy. VPT = Vibration Perception Threshold – mean value of the 24 sites tested for each subject.

Table 2 Mean values (± standard deviation) for assessed gait parameters for two groups under the three testing conditions

	DM group			DPN group		
	Normal walking	Walking and Motor task	Walking and Arith task	Normal walking	Walking and Motor task	Walking and Arith task
Velocity (cm/s)	114.3 (±14.5)	83.3 (±23.7)	89.8 (±18.4)	98.6 (±26.9)	61.5 (±12.6)	73.8 (±29.6)
Step length (cm)	61.7 (±6.8)	49.3 (±9.3)	55.8 (±7.5)	58.5 (±11.6)	42.3 (±9.1)	50.0 (±14.9)
Step time (s)	0.59 (±0.16)	0.61 (±0.09)	0.64 (±0.11)	0.61 (±0.08)	0.69 (±0.08)	0.72 (±0.13)
Double Support (ms)	29.6 (±4.8)	34.5 (±4.3)	31.0 (±2.3)	32.1 (±3.7)	38.9 (±2.7)	36.4 (±6.0)
Cadence (steps/min)	111.3 (±9.8)	100.6 (±13.2)	96.4 (±15.1)	100.0 (±12.3)	87.6 (±9.9)	85.2 (±15.6)

Nor=Normal walking; Motor = walking whilst carrying out a motor task ie. Carrying a tray with cups of water Arith = walking whilst carrying out an arithmetic task ie counting backwards in 7s from a given number. DM group = subjects with diabetes but no peripheral neuropathy and DPN group = subjects with diabetes and peripheral neuropathy

Table 3 – Significance of the between Group and between task interactions for each outcome variable (* denotes a statistically significant difference)

	Velocity	Step Length	Step Time	Double Support time	Cadence
Diabetic patients vs DPN patients	p<0.001*	p=0.013*	p=0.007*	p<0.001*	p<0.001*
Normal walk vs with motor task	p<0.001*	p<0.001*	p=0.145	p<0.001*	p<0.001*
Normal walk vs with arith task	p<0.001*	p=0.016*	p=0.006*	p=0.019*	p<0.001*
Walk with motor task vs walk with arithmetic task	p=0.195	p=0.017*	p=0.398	p=0.013*	p=0.483

Table 4 Gait parameters during normal walking (mean values and standard deviations) and mean percentage change (and standard deviation) values for each with motor and arithmetic tasks.

	Normal Walking		%change with motor task		%change with arithmetic task	
	DM	DPN	DM	DPN	DM	DPN
Velocity (cm/s)	114.3 (14.5)	98.6 (26.9)	-27.6 (15.5)	-35.2 (13.2)	-21.2 (13.0)	-26.9 (13.9)
Step length (cm)	61.7 (6.8)	58.5 (11.6)	-20.2 (10.4)	-26.6 (13.7)	-9.4 (8.4)	-15.5 (13.8)
Step time (s)	0.59 (0.16)	0.61 (0.08)	7.1 (18.8)	13.9 (9.7)	14.6 (28.0)	18.7 (12.8)
Double support time (ms)	29.6 (4.8)	32.1 (3.7)	18.3 (17.3)	22.5 (15.1)	6.6 (13.7)	13.3 (13.5)
Cadence (steps/min)	111.3 (9.8)	100.0 (12.3)	-9.7 (7.7)	-12.0 (7.1)	-13.4 (11.2)	-15.2 (7.9)