A new classification of higher level gait disorders in patients with cerebral multi-infarct states

Richard Liston, Jane Mickelborough, Jacqueline Bene, Raymond Tallis

Hope Hospital, Eccles Old Road, Salford, Manchester, UK

Address correspondence to: R. Liston, Department of Medicine for the Elderly, Tralee General Hospital, Tralee, Co. Kerry, Ireland. Fax: (+353) 66 7126241. Email: listonr@eircom.net or rtallis@fs1.ho.man.ac.uk

Abstract

Background: cerebral multi-infarct states may lead to gait disorders in the absence of cognitive impairment. Where these gait disorders occur in the absence of neurological signs they have been termed gait apraxia or more recently higher-level gait disorders. In this paper we hypothesise three main types based on presumptive sites of anatomical damage: (a) Ignition Apraxia, where damage is predominantly in the supplementary motor area and its connections, with good responses to external clues; (b) Equilibrium Apraxia, where damage is predominantly in the pre-motor area in its connections, with poor responses to external cues and (c) Mixed Gait Apraxia.

Subjects: the clinical features and measured gait parameters of 13 patients with cerebral multi-infarct states and higher-level gait disorder are described (7 with Ignition Apraxia and 6 with Equilibrium Apraxia) along with those of 6 healthy elderly control subjects.

Methods: baseline gait characteristics were assessed on a walkway, which measured the following: step lengths, width of base and velocity.

Results: measured baseline gait parameters support the above hypothesis.

Conclusions: it is suggested, though not proven, that patients with Ignition Apraxia could have problems with internal cueing due to lesions in the supplementary motor area or its connections whereas those with Equilibrium Apraxia could have dysfunction predominantly in the pre-motor area and its connections.

Keywords: higher-level gait disorder, multiple infarcts, classification

Introduction

The association between cerebral multi-infarct states (CMIS) and dementia is well described [1]. It is less well recognised however that CMIS can also lead to severe gait abnormalities in the absence of clinically obvious cognitive impairment or gross neurological signs [2]. The clinical presentation is often one of gait ignition failure, shuffling, freezing, difficulty making turns and disequilibrium in patients with few or any neurological signs accounting for these gait disturbances. Synonyms have included vascular pseudoparkinsonism, arteriosclerotic parkinsonism and lower body parkinsonism [3–5]. Other authors have used the labels gait apraxia, marche à petit pas, frontal ataxia and frontal disequilibrium to describe gaits which have very similar clinical features [6–8] as do the gait abnormalities described in Binswanger’s disease [9].

In an attempt at clarification, Nutt et al. [10] suggested the collective term higher-level gait disorder (HLGD) on the basis that the abnormalities are of the highest sensorimotor systems. Basic motor functions such as power and co-ordination, should therefore be intact as should sensory function with no visual, labyrinthine or proprioceptive deficits discernible. Essentially the abnormal gaits probably represent types of motor programming failure similar to those seen in Parkinson’s disease (PD). He described five types: cautious gait, isolated gait ignition failure, subcortical disequilibrium, frontal disequilibrium and frontal gait disorder. This classification is itself confusing; some gaits are classified according to presumed location (frontal gait disorder), others according to clinical phenomenology (isolated gait ignition failure, cautious gait) and others according to a mixture of the two (frontal disequilibrium, subcortical disequilibrium).
The aim of this paper is to propose a simplified classification of these gait disorders in the context of cerebrovascular disease and to relate the clinical phenomena to possible locations of infarcts within the pathways controlling the motor programming of gait ignition. We will also offer clinical descriptions and objective gait measurements of a small number of patients supporting this new classification. We will be concentrating on patients with CMIS and will refer to their gait disorders as vascular-HLGDs.

Before presenting our proposed classification we would like to review current notions on the mechanism of gait ignition with particular reference to the interaction between the frontal motor areas and the basal ganglia (BG). We shall draw on the ideas about how this system can malfunction with particular reference to PD and how external cueing can improve gait ignition in PD patients. We will then speculate as to how this can give us insights into the pathophysiology of vascular-HLGDs. This, finally, we give as the basis of a new classification which is more conceptually transparent, is more closely related to what is known about normal gait and the effect of locations of lesions and may provide a better framework for developing new therapeutic interventions [11, 12].

The motor programming of gait ignition

The motor cortex contains several distinct areas in the frontal lobes which receive inputs from sensory pathways, motor control structures and modulatory pathways including the thalamus and BG. This cluster of architectonically distinct frontal fields is fundamentally involved in movement planning and performance [13]. The most widely recognised fields are (i) the primary motor cortex (M1) which probably controls muscle force and the direction of movement; (ii) the pre-motor area (PMA) which is probably involved in coupling environmental cues to motor acts and may be responsible for the motor response to external stimuli [14]; and (iii) the supplementary motor area (SMA) which is possibly involved in motor preparation and execution of complex voluntary movements especially if these movements require retrieval of memory, and may thus be responsible for the internal cueing and guidance of learned, skilled, motor acts of the limbs [14–16].

In the case of normal walking – an internally cued, well learned motor act – it has been suggested that the SMA engages in significant firing just prior to gait ignition. This probably reflects preparatory activity for each sub-component of a movement sequence [17]. This preparatory activity may represent sub-movement program selection (i.e. a complex set of instructions for each sub-movement), which is subsequently sent to the M1. It is thought that this SMA activity is switched off by phasic activity generated by the BG, which probably provides a non-specific cue both to trigger the sub-movement (i.e. SMA sends the instructions to the M1) and to instruct the SMA to prepare for the next [18]. This allows the sub-movement to be executed normally and on time [17]. The BG may thus provide the timing cues for switching between sub-movements in an ‘automatic’ movement sequence and also cues new preparatory activity in the SMA. It is this interaction between phasic activity from the BG and pre-motor activity in the SMA, which is responsible for the smooth running of predictable, well-learned, automatic movement sequences which depend on internal cues. The sequence of activations however is different when movements occur in response to external cues. In this situation the BG/SMA pathways could be bypassed with sensory information from the environment feeding directly into the PMA through visual, auditory and proprioceptive pathways, with the PMA subsequently activating the M1 [19].

Classification of higher-level gait disorders

In pathological situations such as PD it has been argued that there is disordered cueing from the BG (most BG output is in fact directed to the SMA) due to a disturbance in internal rhythm formation in the BG such that the SMA is not switched off on time [17, 20]. Sub-movements are therefore not triggered and no new preparatory event occurs in the SMA. It is not surprising therefore that this leads to some of the classical clinical features of PD including gait ignition failure, bradykinesia and freezing. Furthermore, PD patients seem to be greatly disadvantaged by the absence of external cues from the environment and it is likely that in the presence of damage to the BG/SMA pathways, patients rely heavily on intact sensory/PMA pathways to initiate sub-movements [17]. This view is supported by the existing PD literature which shows that a variety of tasks including finger tapping, drawing movements, memory and learning strategies, set shifting and walking are performed better when they are aided by external cues [17, 18, 20–24].

Motor programming failure in Parkinson’s disease and response to external cues

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Pathophysiology of vascular-HLGDs

We hypothesise that an analogous situation may exist in vascular-HLGDs, especially in those patients with ‘parkinsonian’ type gait disorders and we suggest that this is caused by infarction in the SMA or its connections in the periventricular white matter or indeed infarctions in the BG. This is in keeping with Meyer’s original concept of gait apraxia being caused by any mesial frontal lesion which is the anatomical site of the SMA [6]. It is also supported by current evidence suggesting that damage (periventricular white matter lesions or leucoaraiosis) to
critical pathways linking the BG to the ventro-lateral nucleus of the thalamus and to the SMA leads to abnormal gait lines in early vascular dementia [25]. Vascular pseudoparkinsonism can also be caused by frontal or BG infarcts or leucoaraiosis [3]. These critically placed infarcts presumably disrupt the timing cues from the BG in a similar way to PD and may therefore be expected to cause similar gait abnormalities. In support of this view, clinical studies have shown that, as with PD patients [26, 27], patients with vascular-HLGDs [28, 29] find walking easier when responding to external cues e.g. stepping over objects or coloured patterns on the ground. Marsden has hypothesised that the success of these treatments involving external cues may be due to input feeding directly into the PMA from the sensory cortex, bypassing the damaged or de-afferented SMA, as already stated above [19]. However, a significant number of patients with vascular-HLGDs do not have movement ignition and timing problems but present with disequilibrium as their primary complaint [30, 31]. This is clearly consistent with both the original descriptions of HLGDs and is reflected in Nutt’s descriptions, as described above. Our hypothesis for these patients is that the primary disorder is infarction of the sensory/PMA pathways and while they have no difficulties with automatic internally cued movements and as such the BG/SMA pathways are intact, they are unable fully to utilise sensory information from the environment, including proprioceptive, auditory, vestibular and visual information to help initiate and control sub-movements. Such patients are unbalanced, unable to integrate external information into their movement sequences.

Classification based on above hypotheses

We would suggest the following classification of vascular-HLGDs which would link the clinical features with the putative mechanisms of normal gait and the location of pathological damage in a transparent and meaningful way. This classification is summarised in Table 1.

Ignition apraxia

Patients with vascular-HLGDs with predominantly movement ignition difficulties – i.e. gait ignition failure, shuffling, difficulty with turns and freezing – have infarcts in the BG/thalamus/SMA pathways and/or ischaemic lesions in their connections in the periventricular white matter as previously suggested by Fitzgerald and Jankovic [5]. These patients have difficulties primarily with automatic movements which are internally driven. We further hypothesise that these patients’ gait characteristics should improve when externally cued. We suggest this gait disorder be named ignition apraxia. This group will include ‘isolated gait ignition failure’ and possibly some cases of ‘cautious gait’ from Nutt’s classification.

Equilibrium apraxia

Patients with vascular-HLGDs with predominantly disequilibrium have infarcts in the sensory/PMA pathways and/or ischaemic lesions in their connections in the periventricular white matter. These patients have difficulties primarily with externally cued movements; the automatic internal cueing mechanism is normal. The patients’ gait characteristics should not improve when externally cued. We suggest that this gait disorder be named equilibrium apraxia. This group includes ‘sub-cortical disequilibrium’ and ‘frontal disequilibrium’ from Nutt’s classification.

Mixed gait apraxia

Since lesions may affect the connections of both SMA and PMA, it is to be expected that there will be patients with both disequilibrium and gait ignition difficulties as proved in practice. We suggest that this gait disorder be named mixed gait apraxia. This group includes ‘frontal gait disorder’ from Nutt’s classification.

Patient descriptions

Patients

Table 2 summarises the clinical features of 13 typical patients with vascular-HLGDs attending a teaching hospital. Their gait disturbances were out of proportion to the deficits observed in strength, tone, co-ordination and sensation and were not attributable to lack of motivation [6]. All patients’ computerised tomographic (CT) brain
scans showed evidence of significant vascular disease. No patient had significant vestibular, visual, proprioceptive or other significant physical impairments. Their gait parameters were measured using a combination of a gridded inked-foot walkway together with heel and toe switches to obtain the following outcome measures: right and left step length; width of base and velocity [32–36]. No visual or auditory cues were given during the collection of this baseline data. A diagram of the walkway is shown in Figure 1. The method involved placing strips

Table 2. Clinical features of patients

<table>
<thead>
<tr>
<th>Apraxia type</th>
<th>Gait features</th>
<th>Other diagnoses</th>
<th>CT brain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ignition</td>
<td>Ignition failure, shuffling, freezing, MTS = 18/30</td>
<td>TIA, OA</td>
<td>Leukoaraisos</td>
</tr>
<tr>
<td>Ignition</td>
<td>Ignition failure, shuffling, freezing, MTS = 24/30</td>
<td>Hypertension, TIA, dislocated right shoulder, falls</td>
<td>Multiple infarcts incl. basal ganglia</td>
</tr>
<tr>
<td>Ignition</td>
<td>Ignition failure, shuffling, MTS = 27/30</td>
<td>TIA, IHD, peptic ulcer disease</td>
<td>Multiple infarcts incl. basal ganglia, leukoaraisos</td>
</tr>
<tr>
<td>Ignition</td>
<td>Ignition failure, shuffling, MTS = 28/30</td>
<td>Hypertension, TIA, polycythaemia rubra vera</td>
<td>Multiple infarcts incl. basal ganglia</td>
</tr>
<tr>
<td>Ignition</td>
<td>Ignition failure, freezing, MTS = 26/30</td>
<td>Old CVA</td>
<td>Multiple infarcts, leukoaraisos</td>
</tr>
<tr>
<td>Ignition</td>
<td>Ignition failure, shuffling, dysphasia, MTS = 23/30</td>
<td>Old CVA, mitral stenosis</td>
<td>Multiple infarcts, leukoaraisos</td>
</tr>
<tr>
<td>Ignition</td>
<td>Ignition failure, shuffling, freezing, MTS = 21/30</td>
<td>Hypertension, mild hearing impairment</td>
<td>Multiple infarcts, leukoaraisos</td>
</tr>
<tr>
<td>Equilibrium</td>
<td>Disequilibrium, MTS = 28/30</td>
<td>Hypertension, falls</td>
<td>Low density areas – right frontal</td>
</tr>
<tr>
<td>Equilibrium</td>
<td>Disequilibrium, broad based gait, MTS = 28/30</td>
<td>TIA, DM, epilepsy, prostatism</td>
<td>Multiple infarcts, leukoaraisos</td>
</tr>
<tr>
<td>Equilibrium</td>
<td>Disequilibrium, MTS = 20/30</td>
<td>Hypertension, asthma, falls</td>
<td>Leukoaraisos</td>
</tr>
<tr>
<td>Equilibrium</td>
<td>Disequilibrium, short steps, MTS = 26/30</td>
<td>Hypertension, DM</td>
<td>Multiple infarcts incl. basal ganglia</td>
</tr>
<tr>
<td>Equilibrium</td>
<td>Disequilibrium, broad based gait, MTS = 28/30</td>
<td>Hypertension, old CVA, TIA, falls</td>
<td>Multiple infarcts – right frontal and parietal</td>
</tr>
<tr>
<td>Equilibrium</td>
<td>Disequilibrium, MTS = 23/30</td>
<td>Hypertension, hyperthyroidism</td>
<td>Leukoaraisos</td>
</tr>
</tbody>
</table>

TIAs = transient ischaemic attack; OA = osteoarthritis; CVA = cerebrovascular accident; IHD = ischaemic heart disease; DM = diabetes mellitus; incl. = including.

Figure 1. Methodology of data collection.
of inked adhesive moleskin to the outside of the subject’s shoe. The subject then walked down an 8 metre paper-covered walkway. Completed footprint data were converted into co-ordinate data [37] and were analysed using customised software, which calculated right and left step lengths and width of base. Toe and heel footswitches were placed inside the patient’s shoes; on-off activation of which was recorded onto a portable datalogger from which data were downloaded for analysis. These data together with timing data obtained from the breaking of infrared beams allowed calculation of velocity. Three walks were completed and average gait parameter data calculated. Results of these gait measurements are shown in Figure 2.

The gait parameters of 7 Ignition Apraxia (mean age 74.4 ± 10.4 years) subjects and 6 Equilibrium Apraxia subjects (mean age 79.8 ± 5.3 years) are shown in Figure 2 along with the gait measurements of 6 healthy elderly controls (mean age 68.3 ± 2.8). These elderly controls were healthy relatives of day hospital attendees who were identified opportunistically. The three groups were quite distinct with respect to right step length ($P<0.01$), left step length ($P<0.01$), width of base ($P<0.05$) and velocity ($P<0.01$). These measured baseline gait parameters are consistent with the above hypothesis.

**Discussion**

We acknowledge that this is a difficult area where clinical phenomena and presumed lesions are often loosely linked together without clear-cut proof. It is however the first attempt to put a theoretical framework on what have heretofore been clinical descriptions only. Our clinical descriptions and objective gait parameters do suggest that the groups may be distinct but more research will clearly be required to prove this. Presence or absence of responses to visual and auditory cues may help provide this evidence along with neuroradiological correlation. It may be that functional imaging with positron emission tomography will in future help indicate whether PMA or SMA dysfunction is actually occurring as hypothesised. Alternatively selection of patients with similar CT abnormalities such as those with isolated severe leukoaraiosis [38] could also yield valuable information. Such investigation, in parallel with more detailed gait analysis and cue-response testing of a larger population of patients is the logical next step.

The origin and significance of patchy low-density changes seen in the peri-ventricular white matter on both CT and magnetic resonance (MR) scanning has been the subject of much debate in the literature. Hachinski [38] first used the non-specific term leukoaraiosis, to avoid
implying an aetiological mechanism. Recent studies do however suggest that leukoaraiosis is associated with gait impairment, worse equilibrium scores and falls [39–44]. Some authors argue that these gait disorders may exist in mild subclinical forms associated with mild periventricular changes. Clearly a severe gait disorder occurs in Binswanger’s disease in association with severe leukoaraiosis [9]. As stated above leukoaraiosis could disconnect frontal regions involved in gait initiation from the basal ganglia and sensory pathways.

Although we have concentrated on patients with vascular disease in this paper it is clear that other groups with gait apraxia such as those with normal pressure hydrocephalus or frontal lobe tumours can also be accommodated within our classification. Frontal lobe tumours could disrupt SMA or PMA function in the same way as an infarct leading to Ignition Apraxia and normal pressure hydrocephalus could interrupt the periventricular white matter in the same way as leukoaraiosis does. We suggest finally that this classification is probably consistent with all HLGDs irrespective of underlying pathology.

**Key points**
- Current classifications of higher-level gait disorders are confusing.
- Lessons from normal gait and the existing PD literature may allow for better understanding.
- Patients with Ignition Apraxia may have damage to loops involving the supplementary motor area and basal ganglia.
- Patients with Equilibrium Apraxia may have damage to loops involving the sensory cortex and pre-motor area.
- Clinical observation supports a new classification.

**Ethics and consent**

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